CMS HIGHLIGHTS + LHC COMPUTING

Federico Vazzoler, *on behalf of the DESY CMS group*

97th meeting of the DESY Physics Research Committee
Hamburg, 24 April 2024

OVERVIEW

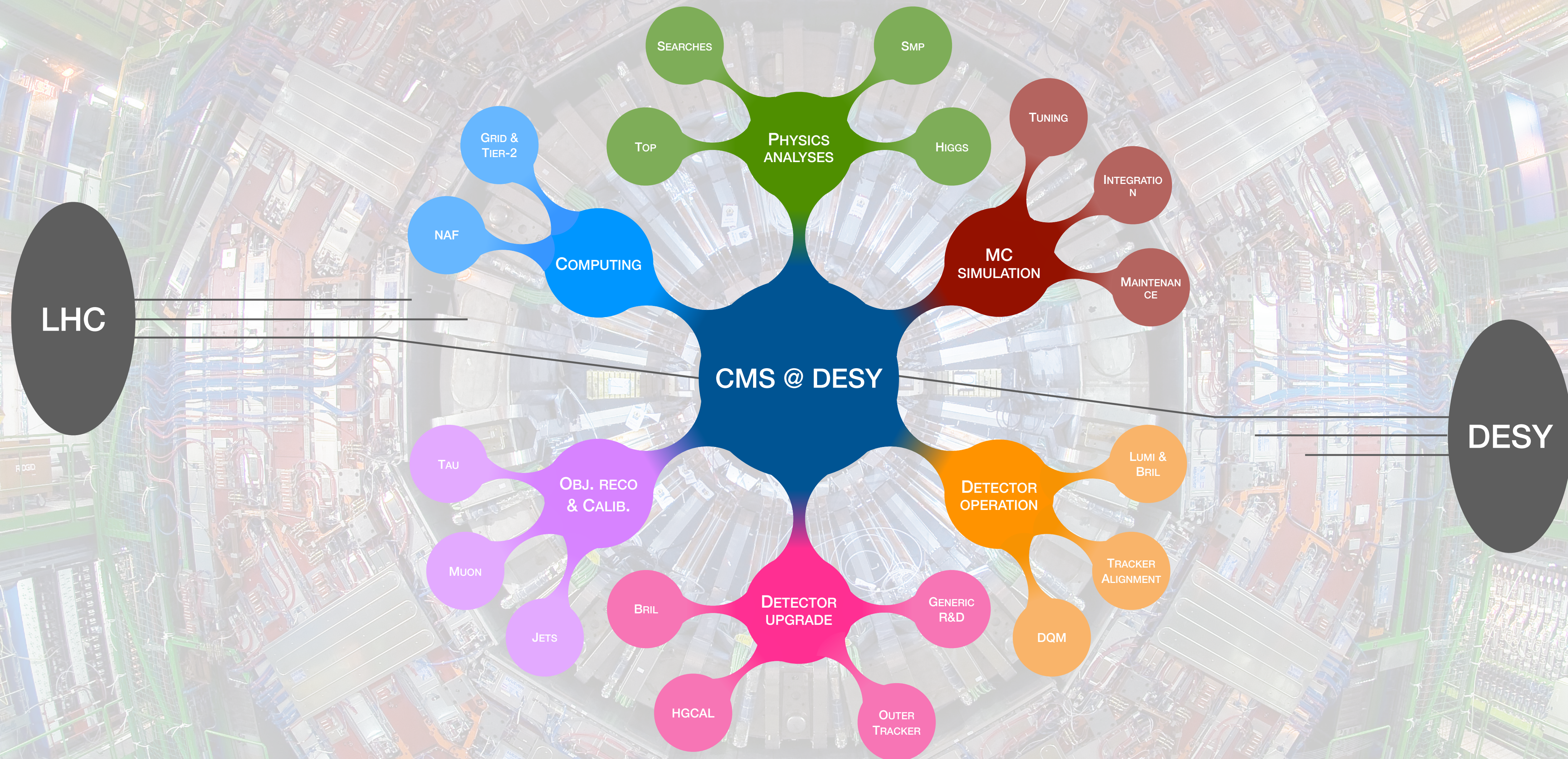## PHYSICS HIGHLIGHTS

▸ Extraction of $\sin^2 \theta_{\text{eff.}}^{\ell}$ @ 13 TeV

▸ $VH(\rightarrow bb)$ legacy analysis

▸ b-associated H production

▸ Review of $X \rightarrow YH$ searches

▸ First simultaneous measurement of ttZ, tWZ and tZq

▸ Search for Dark Matter produced in association with a single-t or $t\bar{t}$ pairs
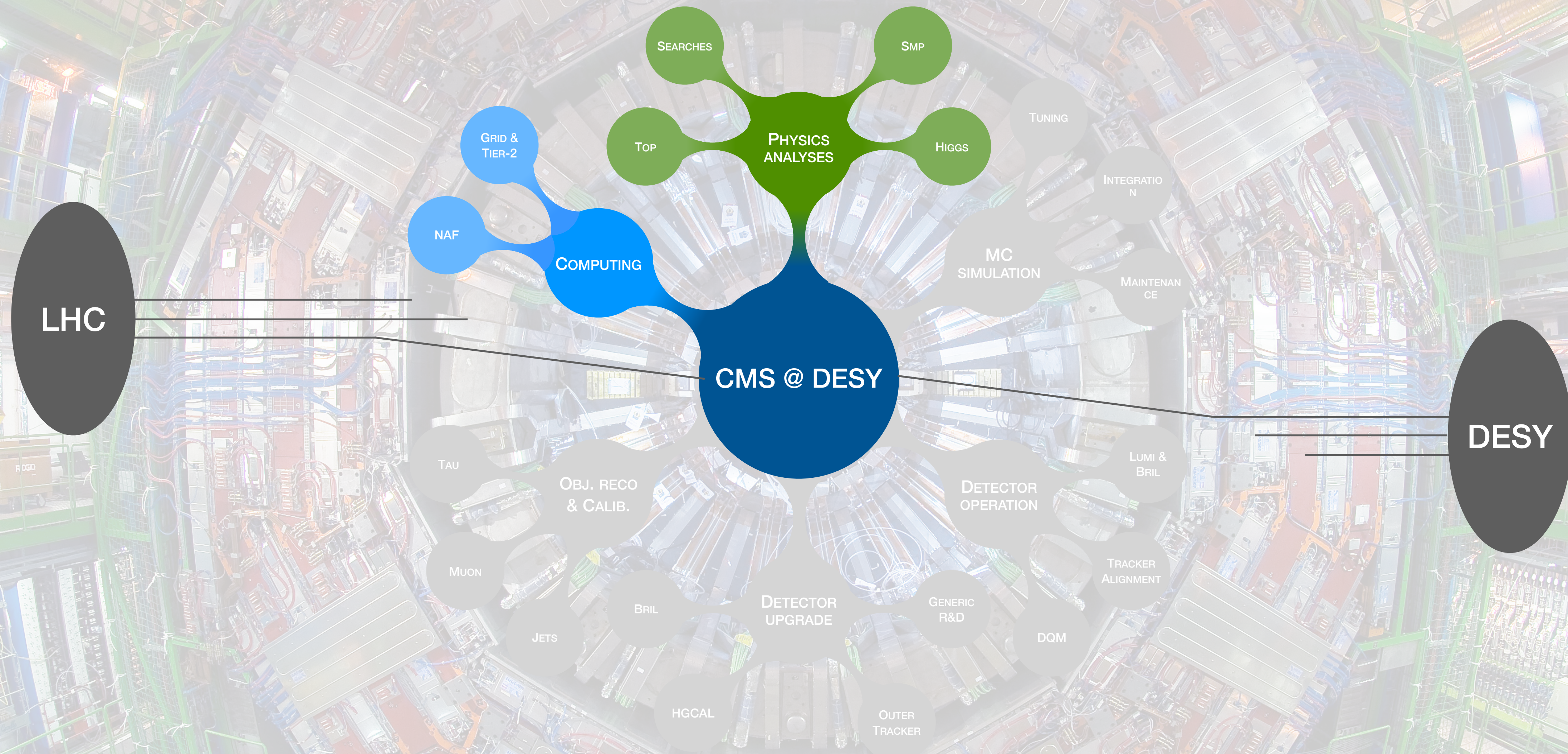
LHC COMPUTING
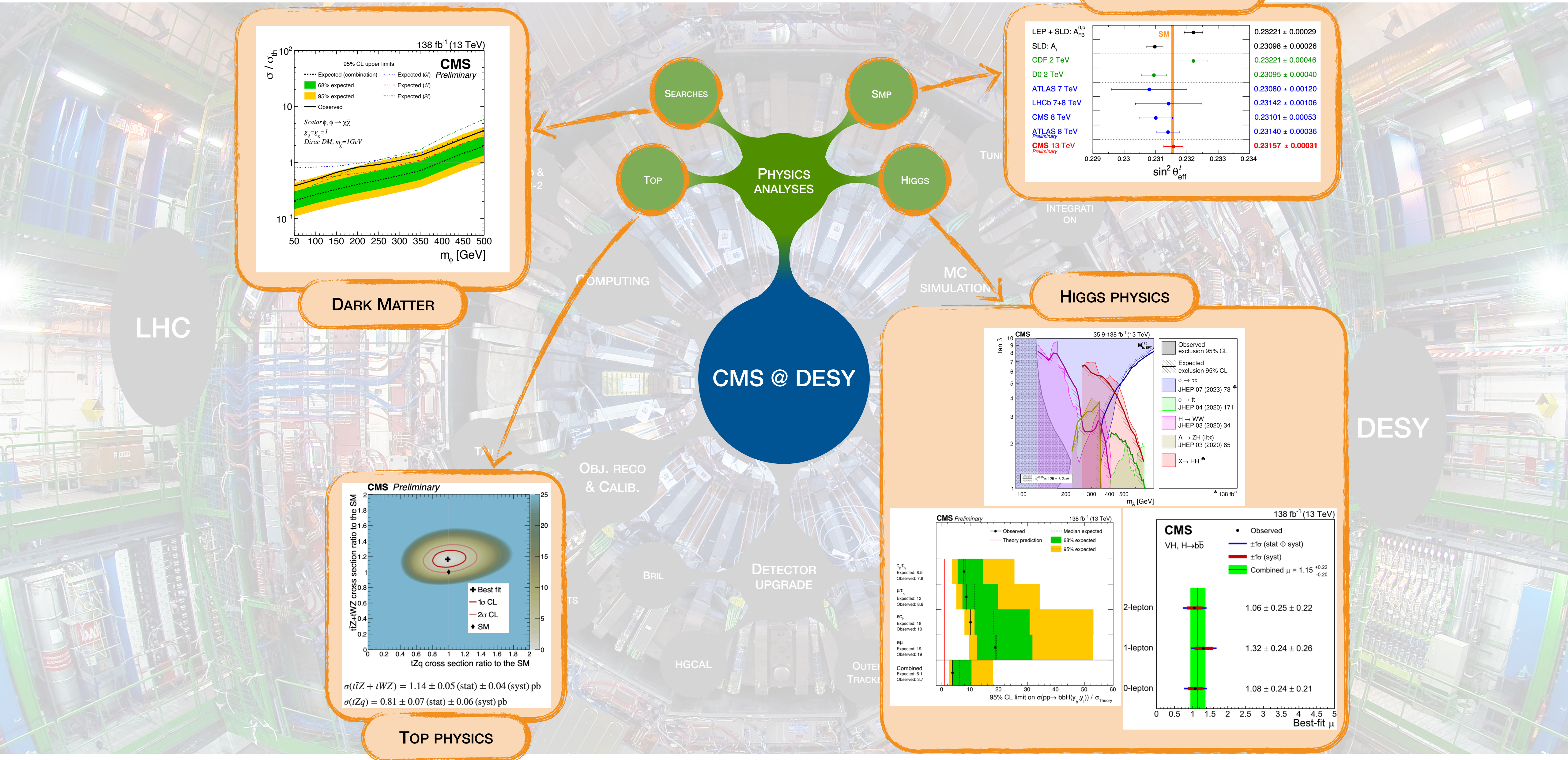
SUMMARY

THE CMS GROUP @ DESY

THE CMS GROUP @ DESY

PHYSICS HIGHLIGHTS

STANDARD MODEL

SEARCHES

SMP

TOP

PHYSICS ANALYSES

HIGGS

TUNING

INTEGRATION

COMPUTING

MC SIMULATION

DARK MATTER

CMS @ DESY

LHC

DESY

OBJ. RECO & CALIB.

HIGGS PHYSICS

BRIL

DETECTOR UPGRADE

HGCAL

OUTER TRACKER

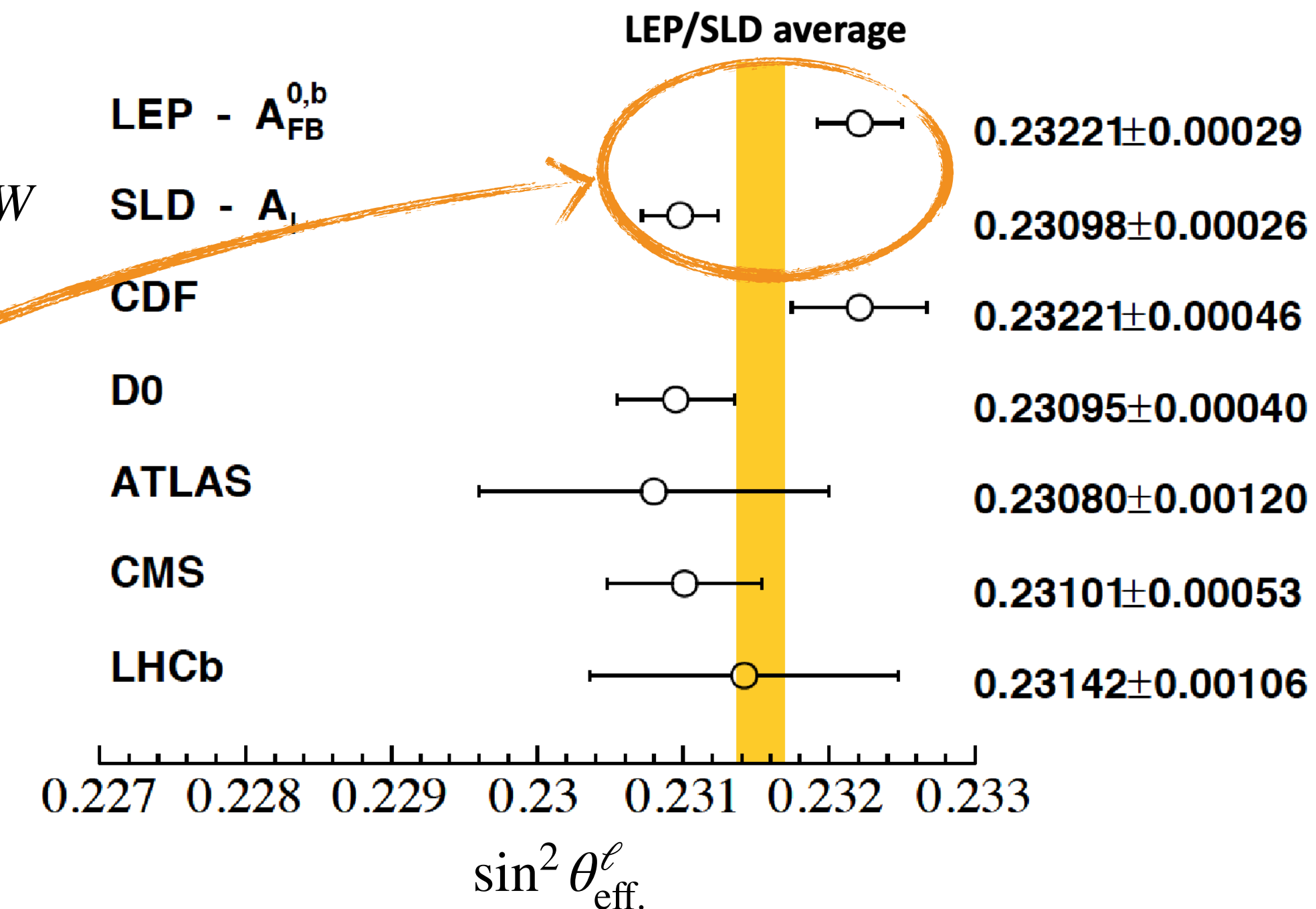TOP PHYSICS

EXTRACTION OF $\sin^2\theta_{\text{eff.}}^{\ell}$ @ 13 TEV

▸ EW mixing angle is a **key** parameter in the SM:

- Relates the masses of the EW vector bosons $\sin^2\theta_W = 1 - m_W^2/m_Z^2$

- Governs the strength of the neutral component of the weak interaction

▸ At higher orders in EW → define an "effective quantity" $\sin^2\theta_{\text{eff.}}^{\ell} = \kappa_\ell \sin^2\theta_W$

▸ Very precise calculation in the SM: $\sin^2\theta_{\text{eff.}}^{\ell} = 0.23155 \pm 0.00004$

▸ Two most precise measurements from lepton colliders (LEP, SLD)
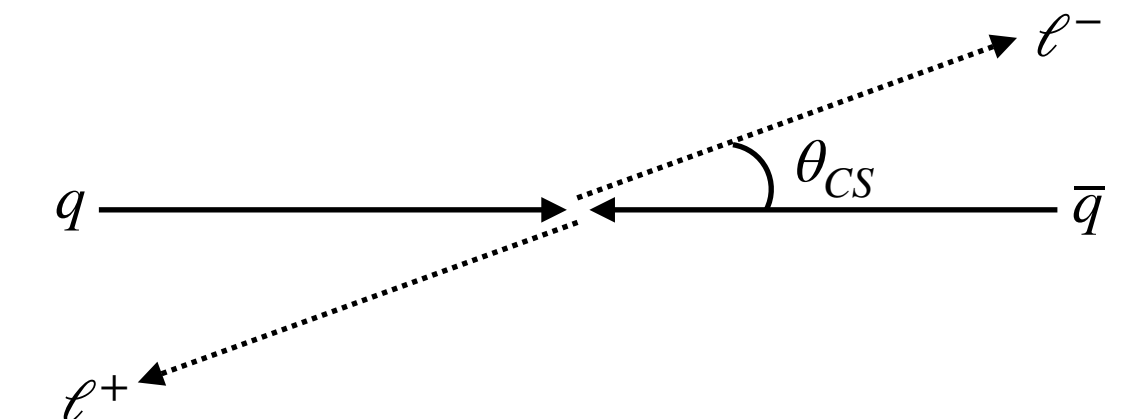→ Some tension, potential hint for NP

▸ Overall test of the EW sector

$$\delta \sin^2\theta_{\text{eff.}}^2 \bigg|_{\text{world avg.}} = 0.00016 \longrightarrow \delta m_w = 8\,\text{MeV}$$

	LEP/SLD average
LEP - $A_{FB}^{0,b}$	0.23221 ± 0.00029
SLD - A_l	0.23098 ± 0.00026
CDF	0.23221 ± 0.00046
D0	0.23095 ± 0.00040
ATLAS	0.23080 ± 0.00120
CMS	0.23101 ± 0.00053
LHCb	0.23142 ± 0.00106

$\sin^2\theta_{\text{eff.}}^{\ell}$

EXTRACTION OF $\sin^2\theta^\ell_{\text{eff.}}$ @ 13 TeV
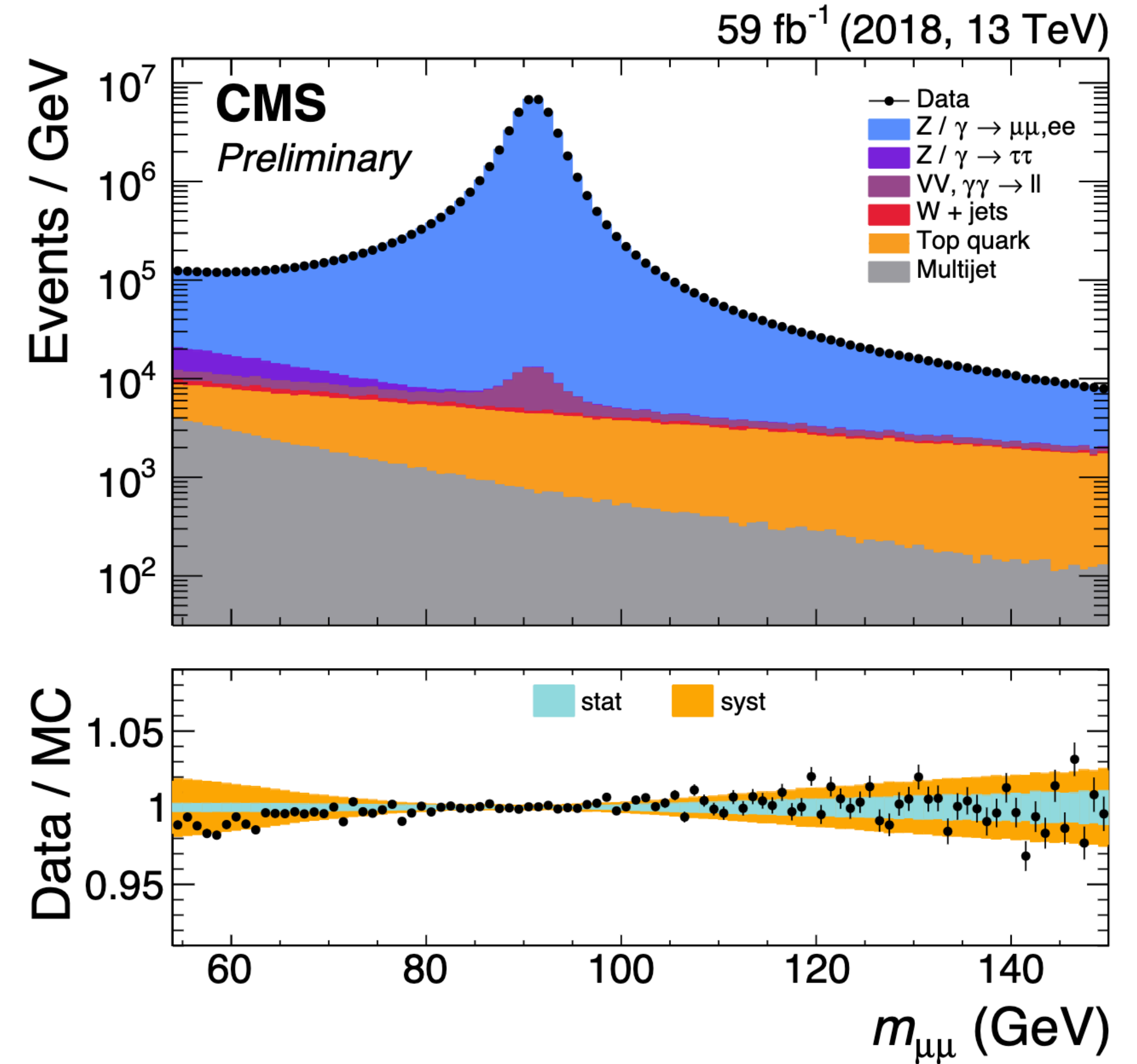
▸ Use $pp \to Z/\gamma^* \to \ell^+\ell^-$ events collected at 13 TeV, full LHC Run 2

▸ Presence of axial and vector-axial couplings (and EW mixing angle)
→ non-zero forward-backwards asymmetry A_{FB}
→ sensitive to the $\sin^2\theta^\ell_{\text{eff.}}$ value

▸ New CMS measurement, extreme experimental challenge:

• Included electrons outside tracker/only in forward calorimeter

• $|\eta|$ acceptance up to 4.36
→ increased sensitivity to A_{FB}

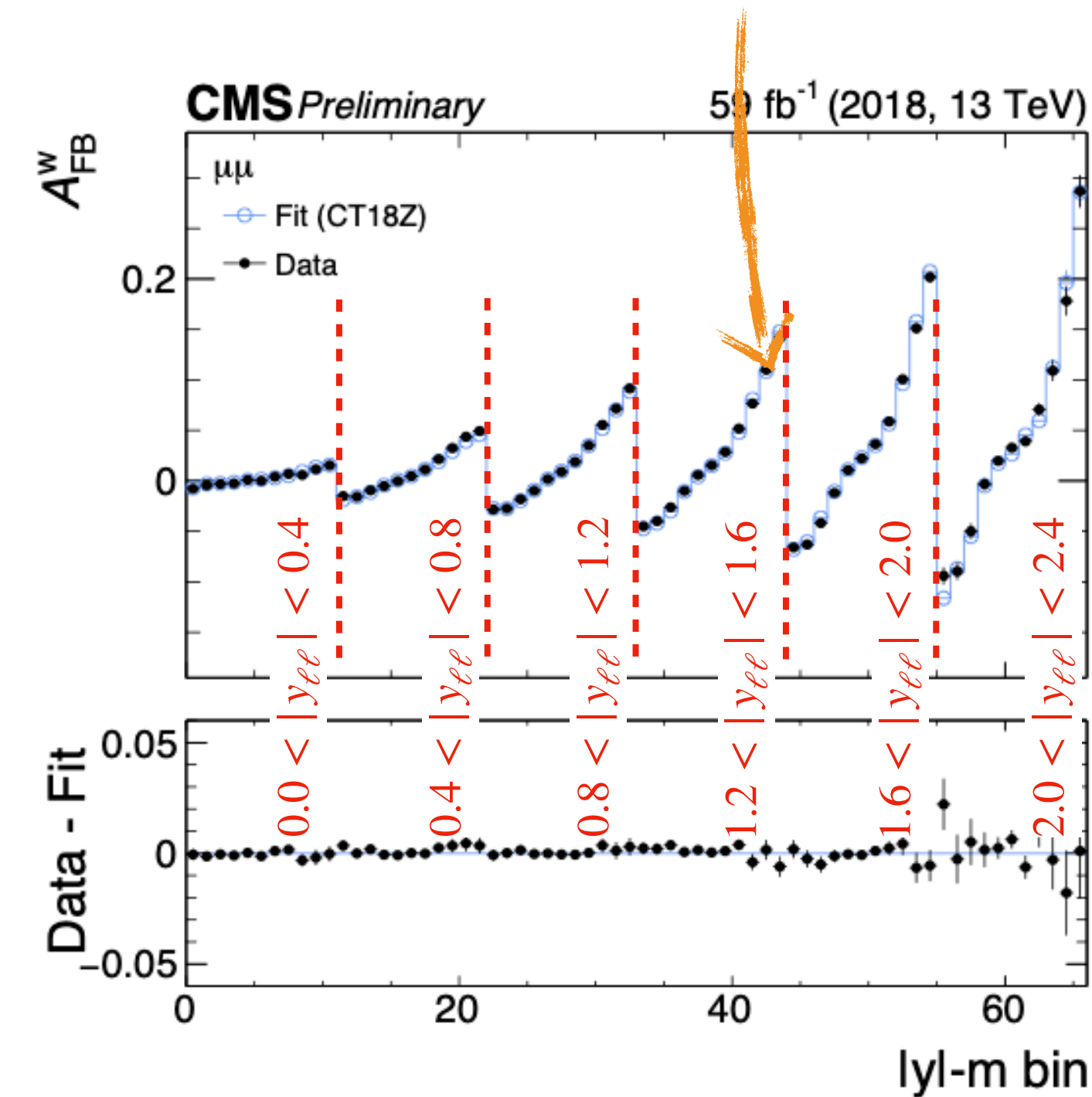$$\frac{d\sigma}{d\cos\theta_{CS}} \propto \left[\frac{3}{8}A(1+\cos^2\theta_{CS}) + A_{FB}\cos\theta_{CS}\right]$$

$$A_{FB} = \frac{N(\cos\theta_{CS} > 0) - N(\cos\theta_{CS} < 0)}{N(\cos\theta_{CS} > 0) + N(\cos\theta_{CS} < 0)}$$

59 fb^{-1} (2018, 13 TeV)

CMS
Preliminary

Events / GeV

Data
$Z/\gamma \to \mu\mu, ee$
$Z/\gamma \to \tau\tau$
$VV, \gamma\gamma \to ll$
W + jets
Top quark
Multijet

Data / MC

stat   syst

$m_{\mu\mu}$ (GeV)

EXTRACTION OF $\sin^2\theta_{\text{eff.}}^{\ell}$ @ 13 TeV

Extract $\sin^2\theta_{\text{eff.}}^{\ell}$ from fit to A_{FB} using high-precision theory model

Choice of PDFs in the model is crucial!

Best hadron collider measurement

The CMS experiment at CERN measures a key parameter of the Standard Model

With this measurement the LHC is again demonstrating its ability to provide very high-precision measurements and bringing new insights into an old mystery
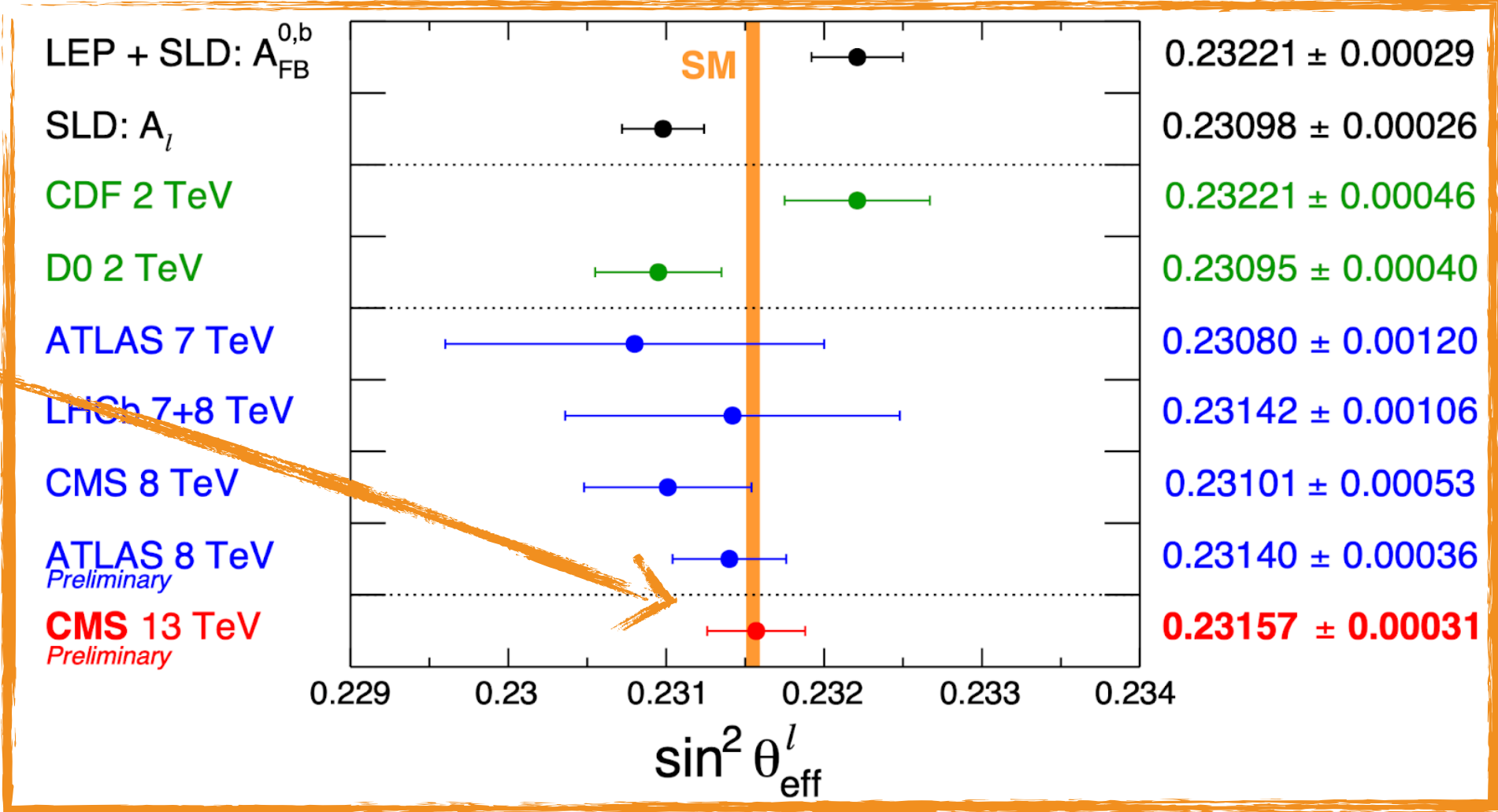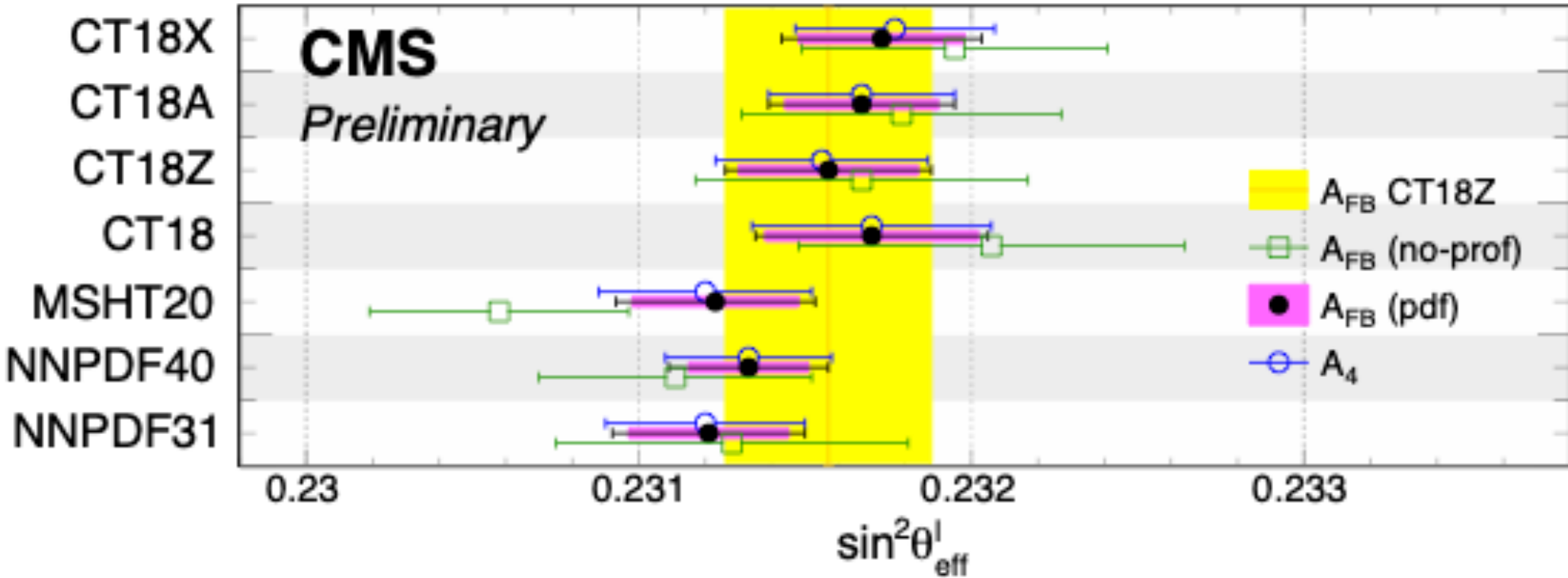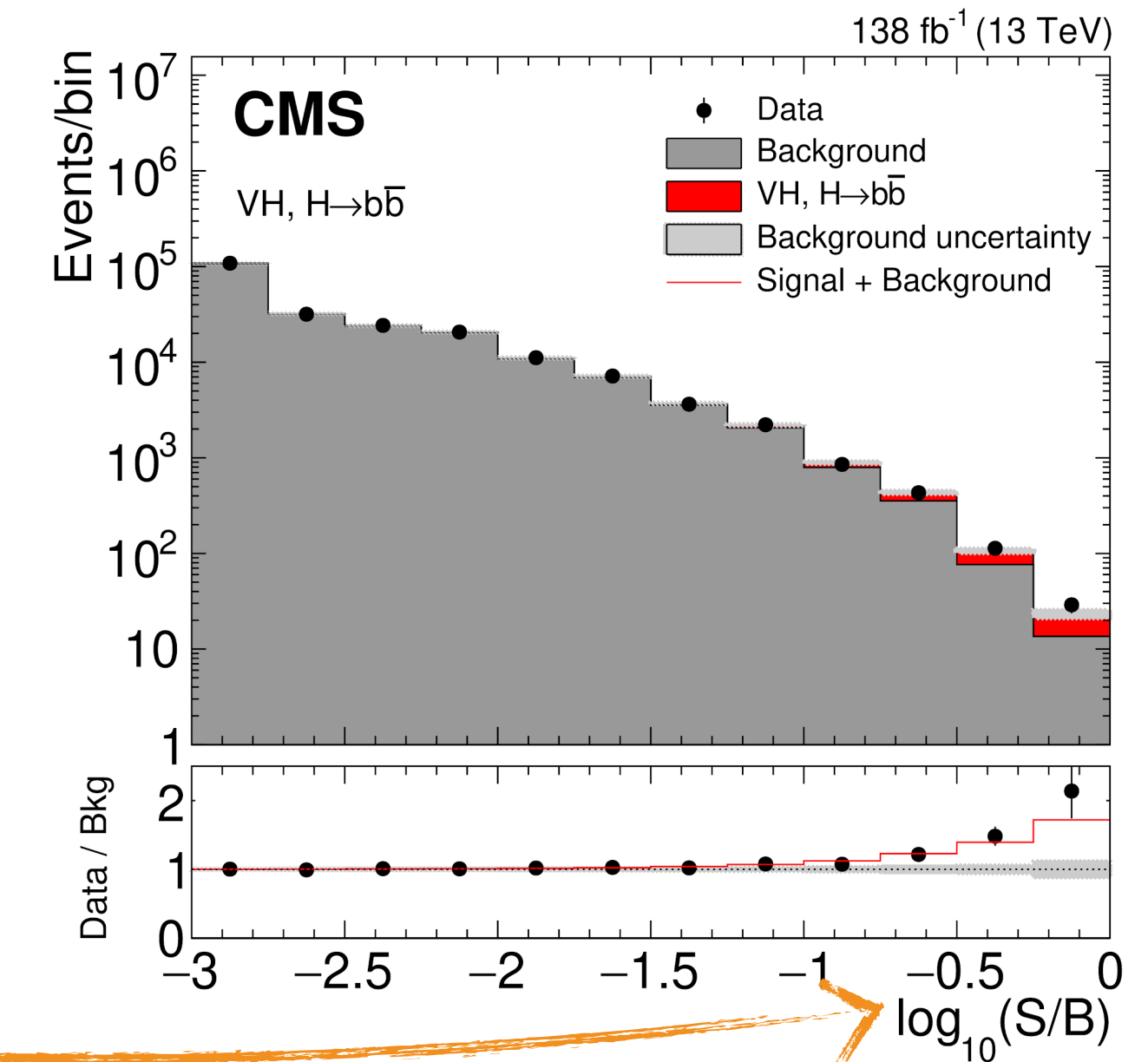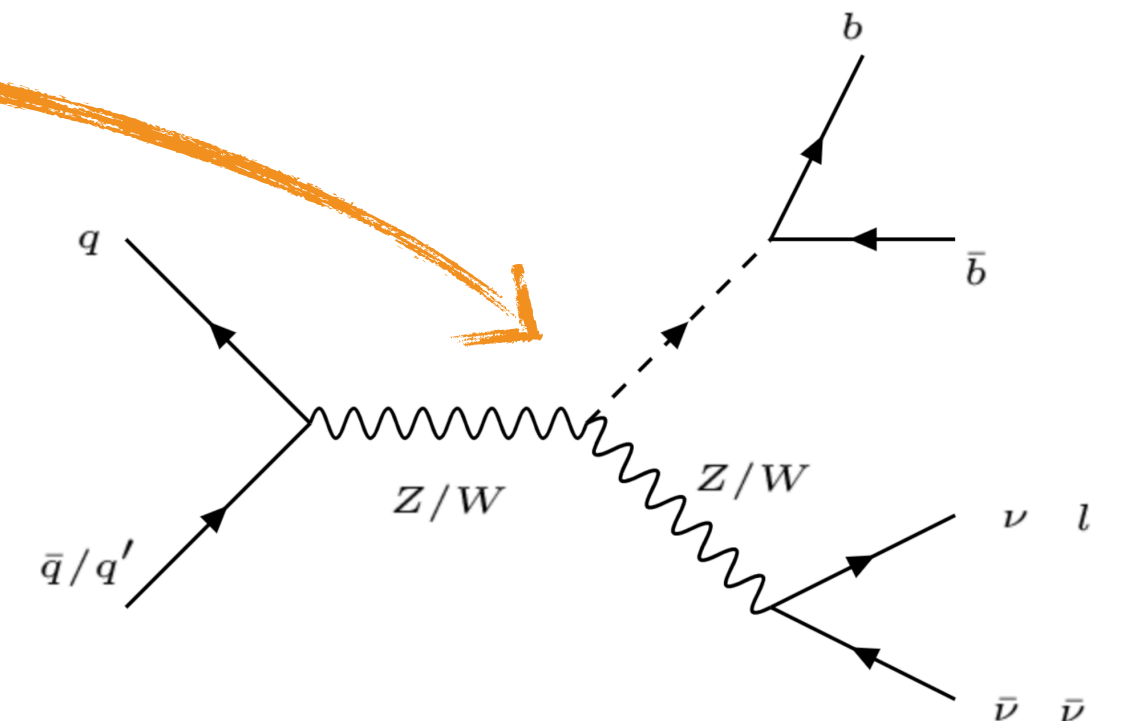
News | Physics | 03 April, 2024

Press-releases from CERN and DESY!

$0.00010\ (\text{stat.}) \pm 0.00015\ (\text{syst.}) \pm 0.00009\ (\text{theo.}) \pm 0.00027\ (\text{PDF})$

$VH(\to bb)$ LEGACY ANALYSIS

▸ Golden production mode for $H \to bb$ channel

▸ Three V boson channels: $Z \to \nu\nu$, $W \to \ell\nu$ and $Z \to \ell\ell$ (where $\ell = e, \mu$)

▸ Simultaneous analysis of resolved and boosted $H \to bb$

▸ Signal extraction with Deep Neural network (DNN)

▸ Inclusive measurement with observed (expected) significance of $6.3\,\sigma$ $(5.6\,\sigma)$

▸ Combined inclusive signal strength: $\mu = 1.15^{+0.22}_{-0.20}$

▸ Perfect agreement with the SM prediction in all the channels
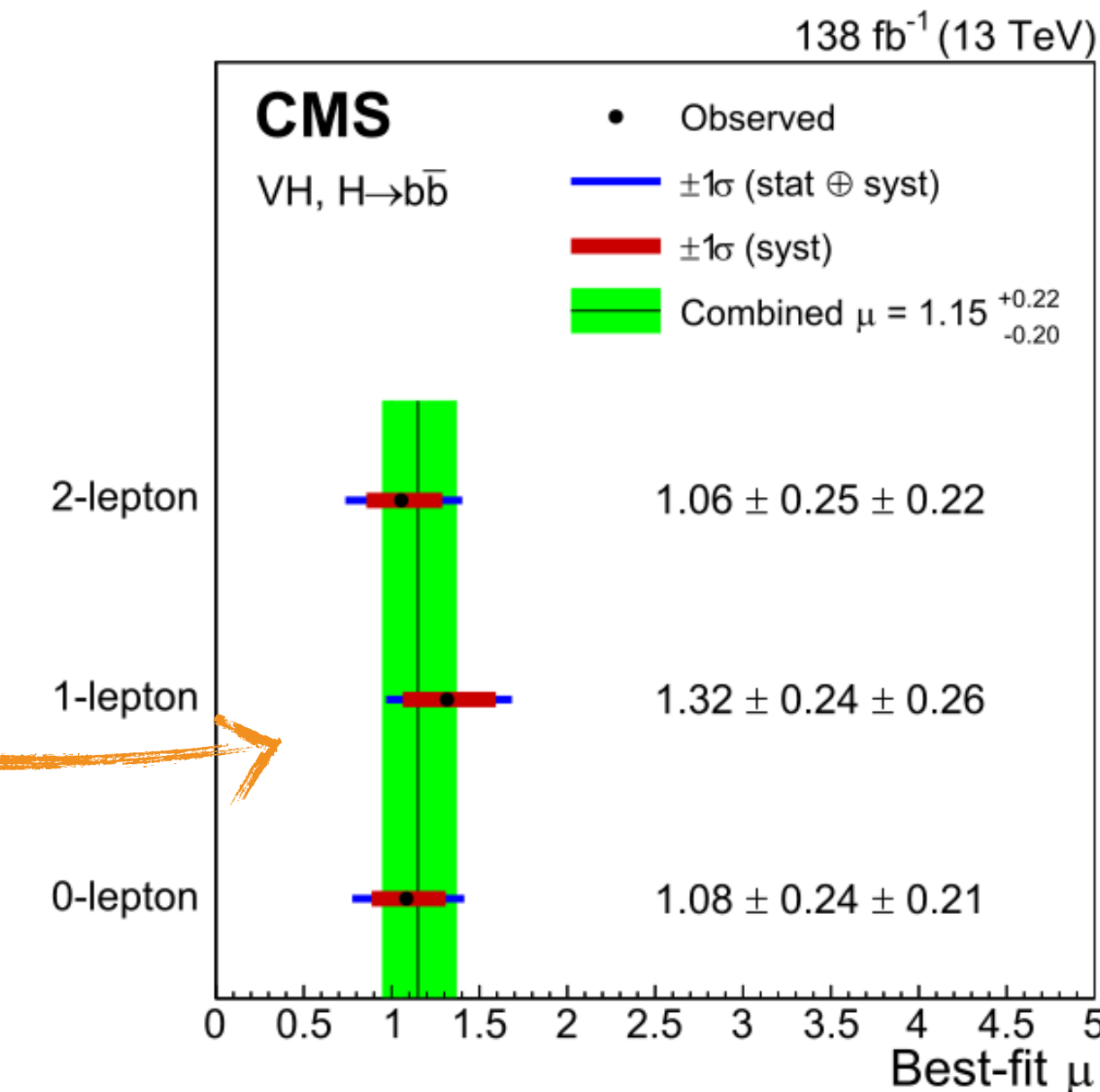
$VH(\to bb)$ LEGACY ANALYSIS

‣ LHC Run 2 → differential analysis:

- Simplified Template Cross-Section (STXS) = probe kin. properties of the H in a model-independent way

- Some bins merged w.r.t. standard STXS stage 1.2

‣ Boosted topology → highest p_T^V split at $400\,\text{GeV}$:

- Very good reach in the high p_T^V region

- Improve sensitivity to BSM effects

- First step toward EFT study (in progress)

b-ASSOCIATED H PRODUCTION
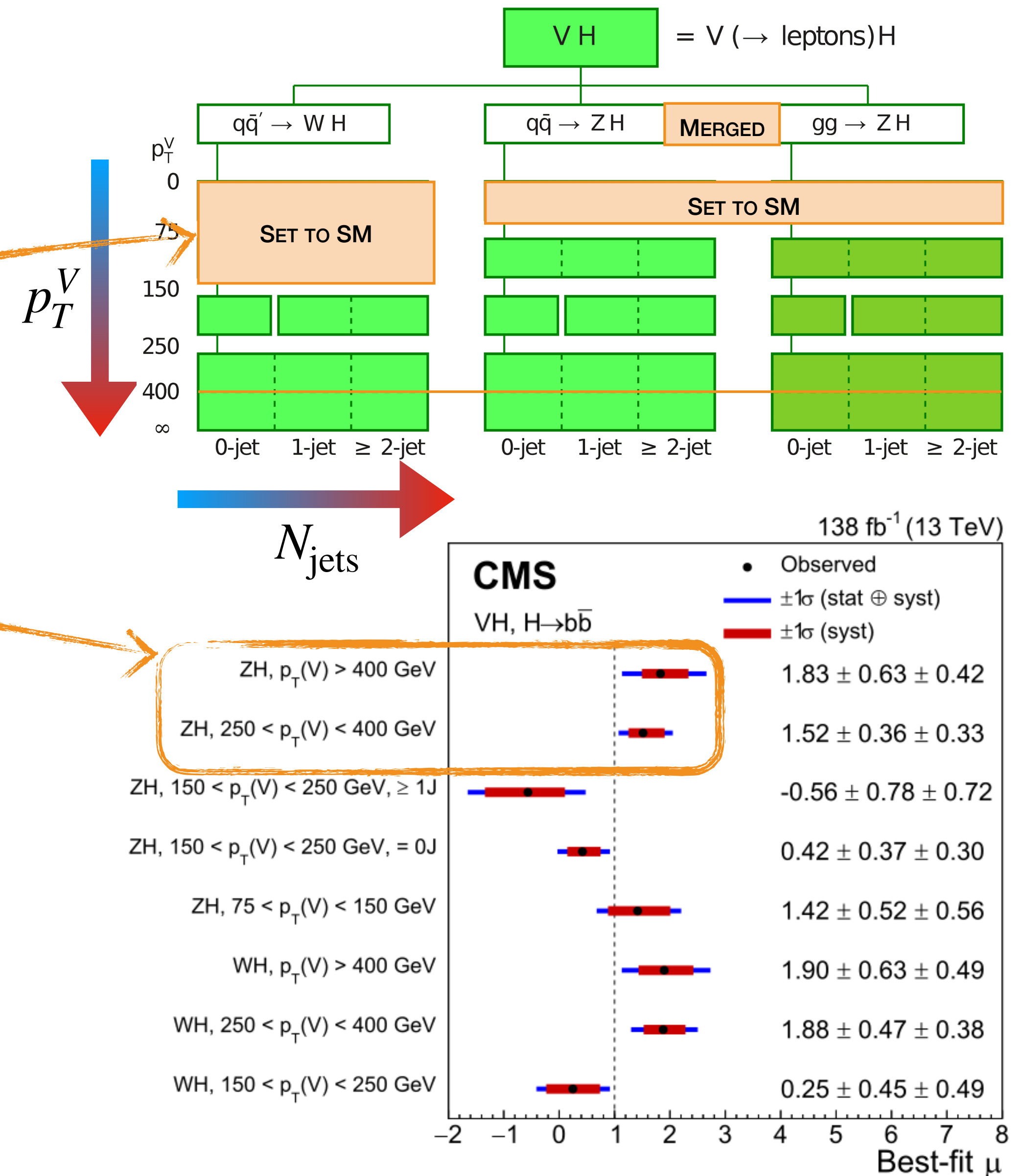
▸ **First dedicated measurement** of H boson production in association with b-quarks

- Rate comparable to ttH production
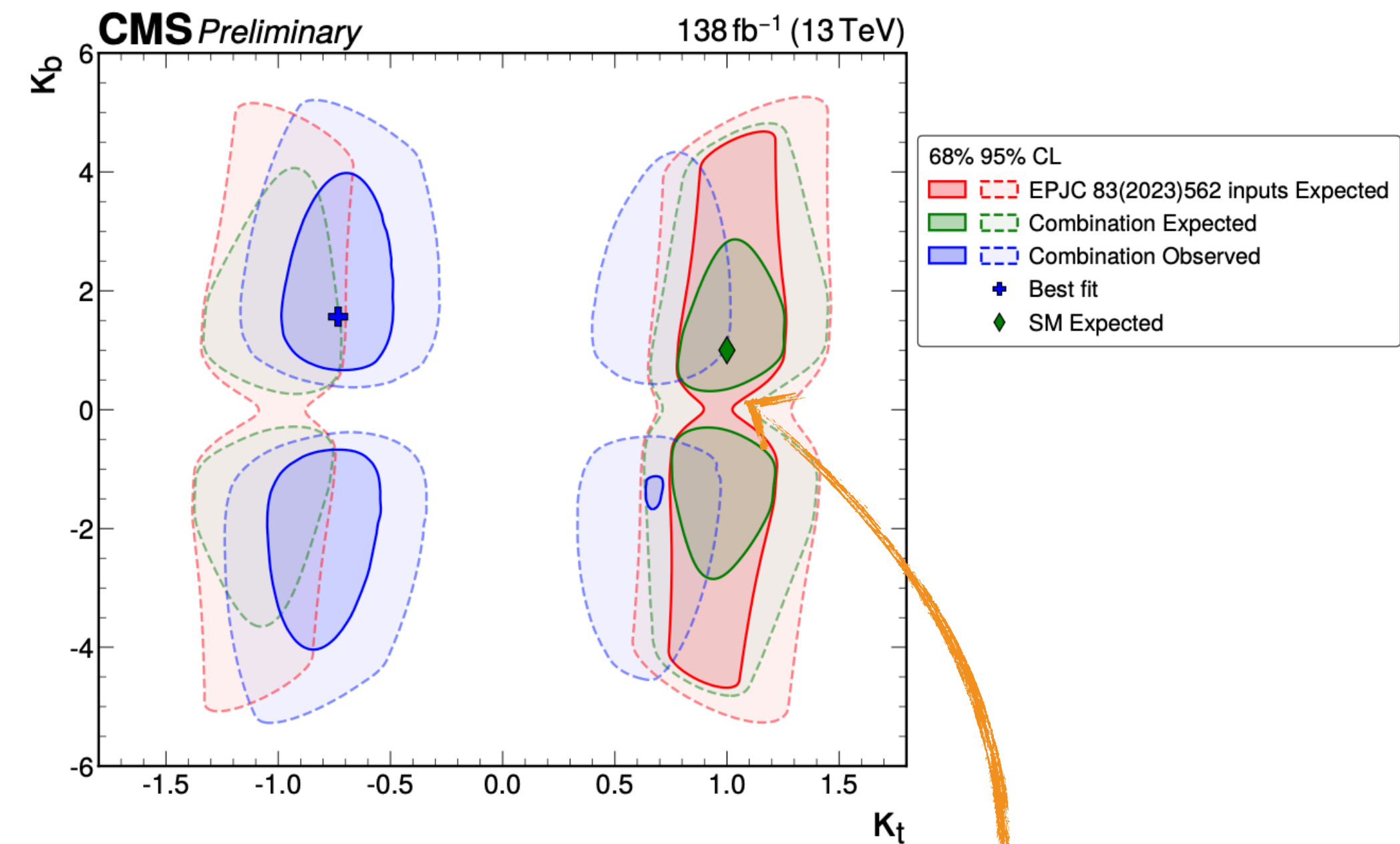
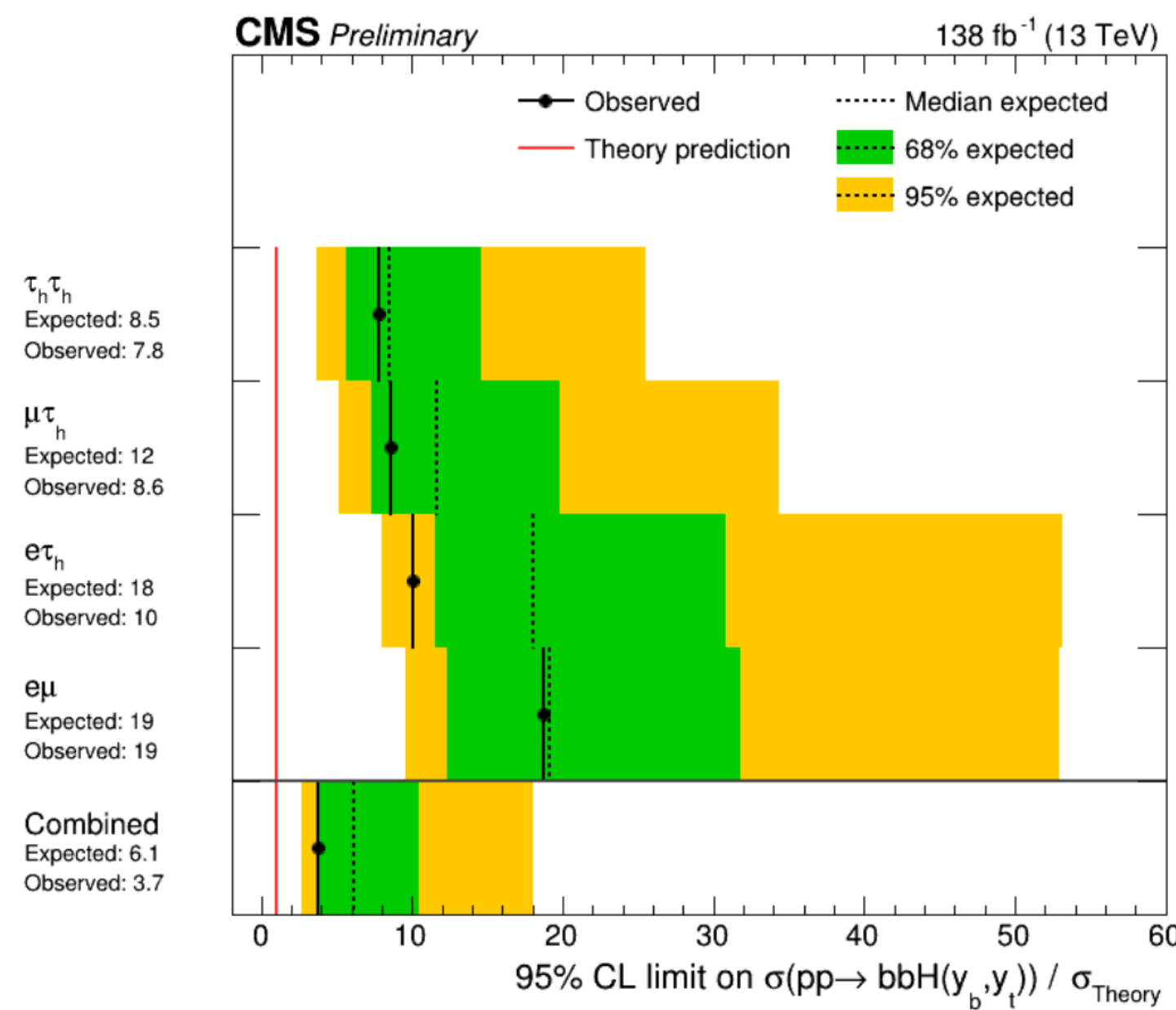- Challenging signature
  → larger background
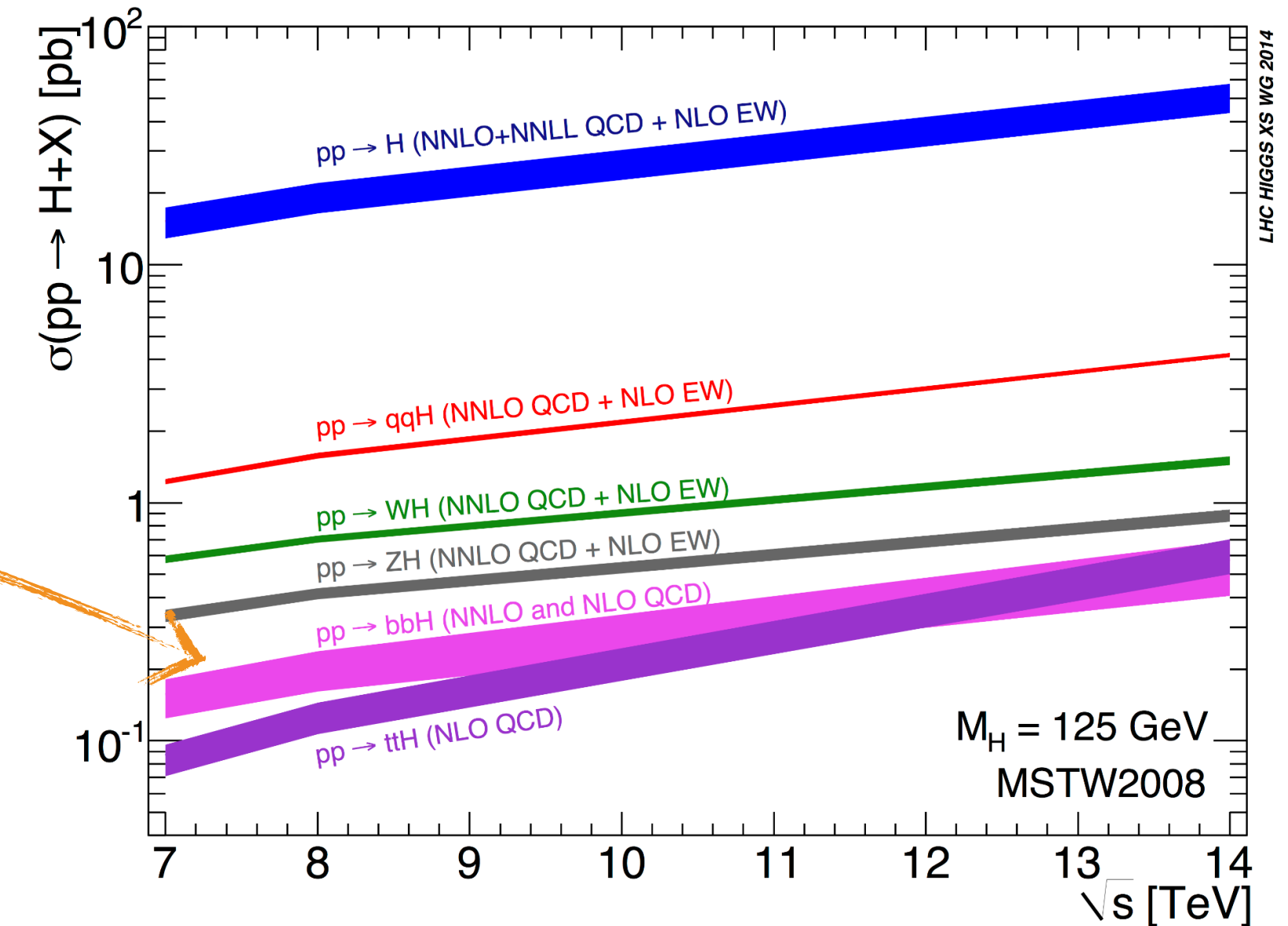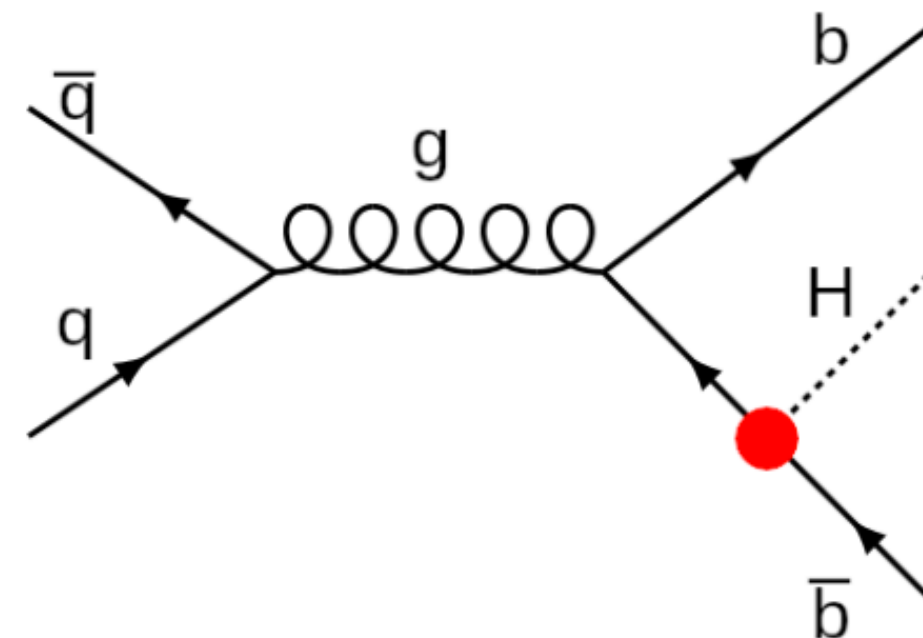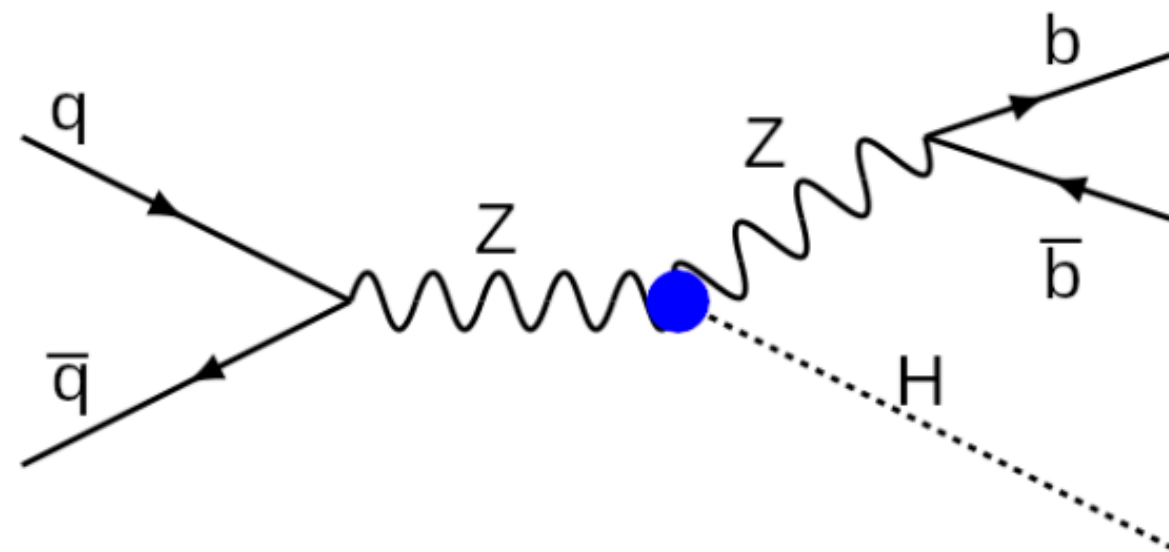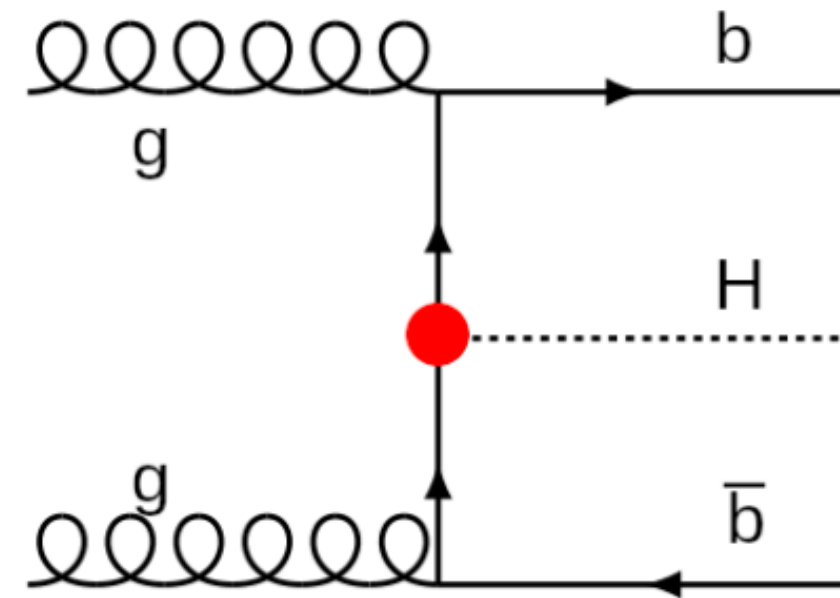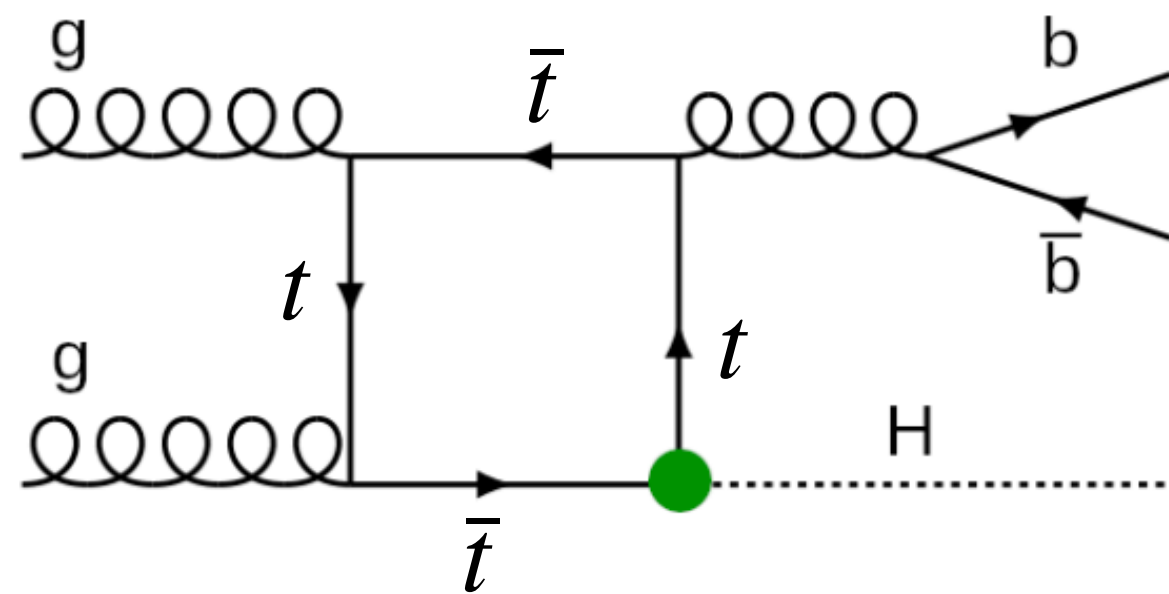
▸ Contributions from diagrams involving:

- top (κ_t^2)

- bottom (κ_b^2)

- interference ($\kappa_t \kappa_b$)

▸ Decay modes targeted: $H \to \tau\tau$ and $H \to WW \to \ell\nu\ell\nu$

b-ASSOCIATED H PRODUCTION

‣ Multivariate analysis (BDT) used to separate signal from backgrounds (electroweak, $t\bar{t}$, QCD multimeter, H production w/o b jets)

‣ Signal extracted from distribution of the BDT scores

‣ Upper Limit (UL) at 95% Confidence Level (CL) on $\sigma(pp \to bbH)/\sigma_{th.}$: 3.7 observed (6.1 expected)

‣ Constraints on (κ_b, κ_t) derived in combination with the CMS $H \to \tau\tau$ analysis (vetoing b-jets) → **first** use of b-associated production of H to constrain κ_b and κ_t

REVIEW OF $X \to YH$ SEARCHES

▸ Comprehensive review of BSM searches for H production through heavy resonances $X \to HH$, YH and VH channels

▸ Many important **new developments**:

- Sensitivity in the HH and YH combinations + projections for HL-LHC

- Study finite width approximation and interference effects

▸ **Strong upper limits and constraints** in parameter space of **extended H sector** (MSSM) and warped extra dimension models
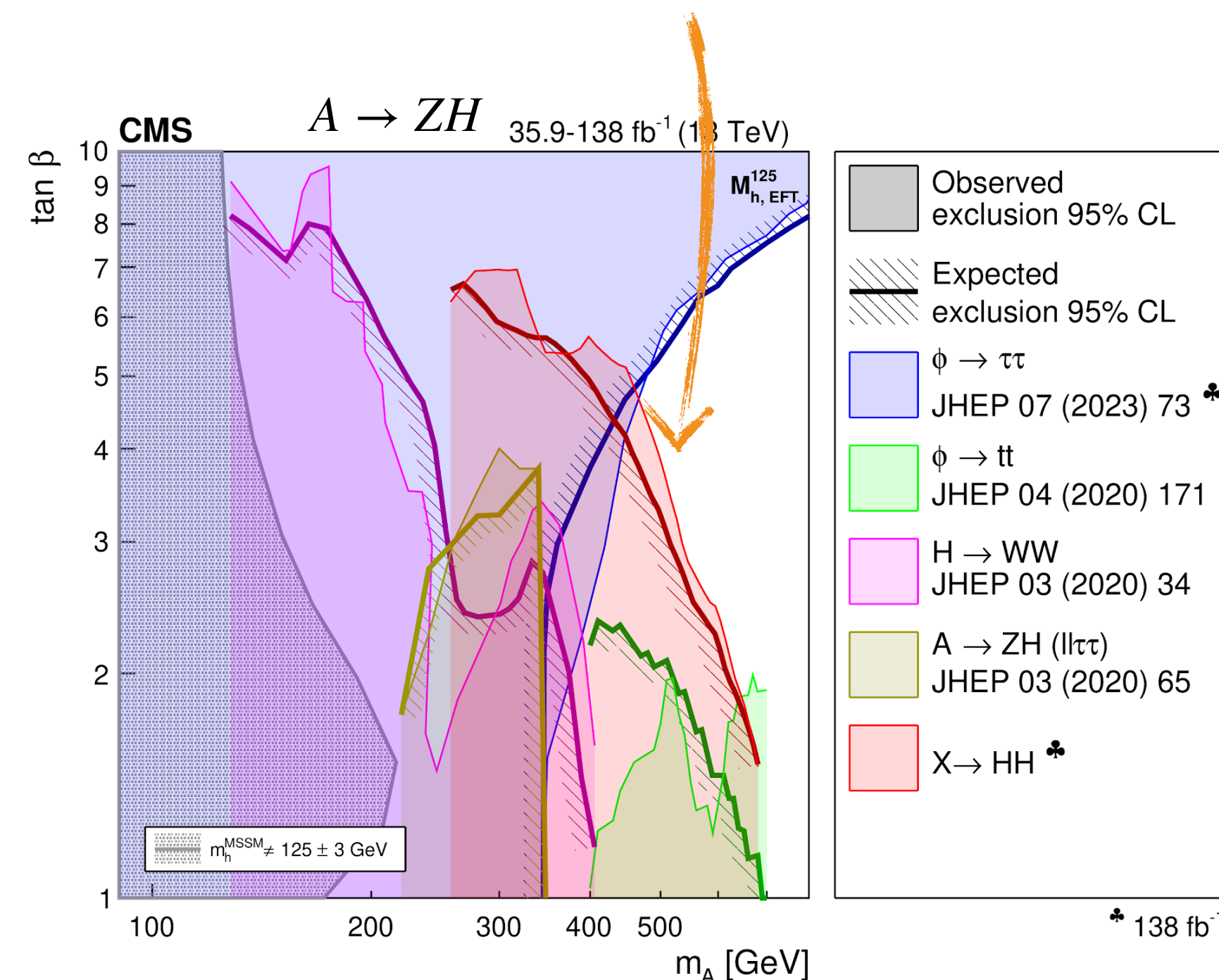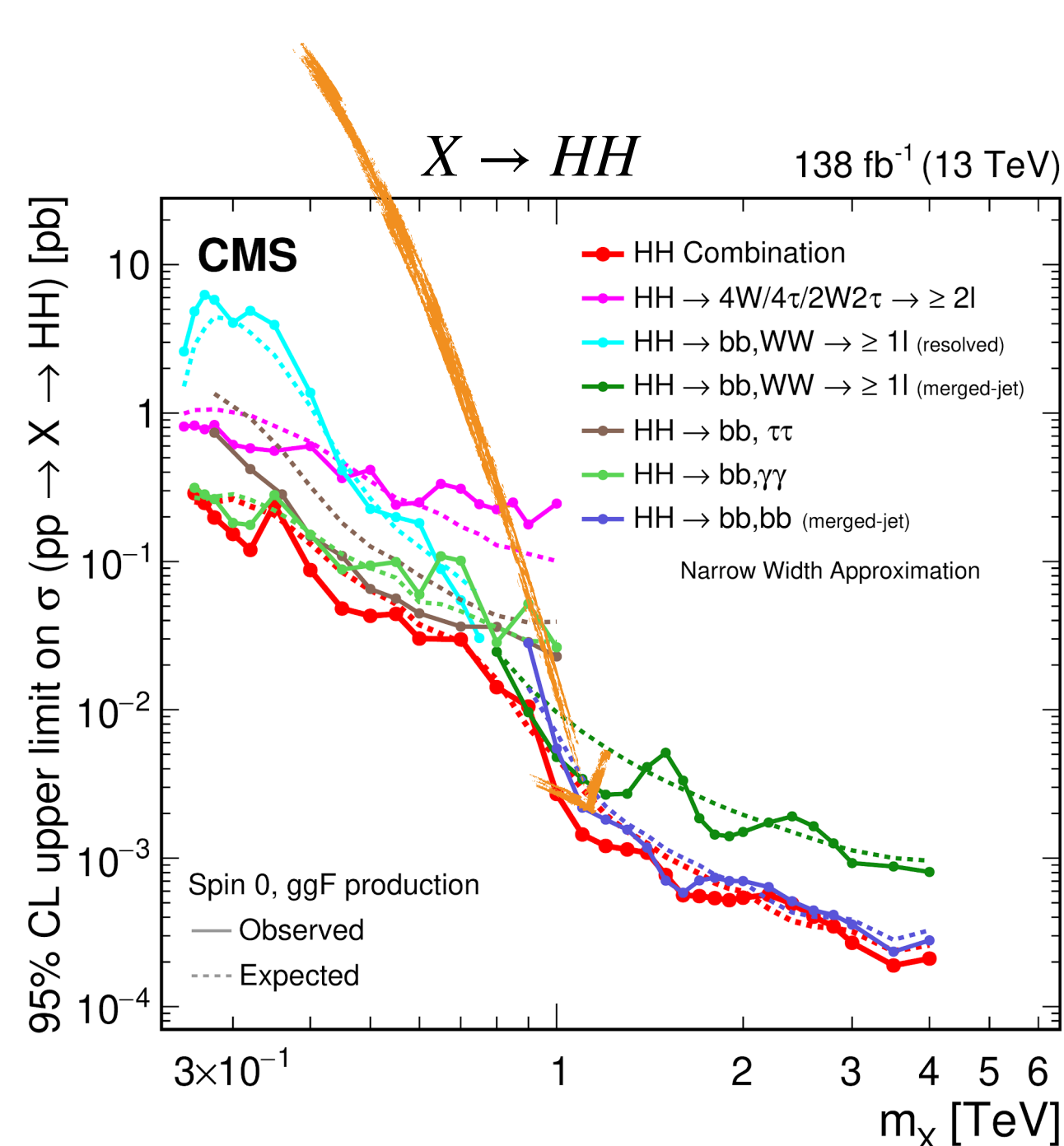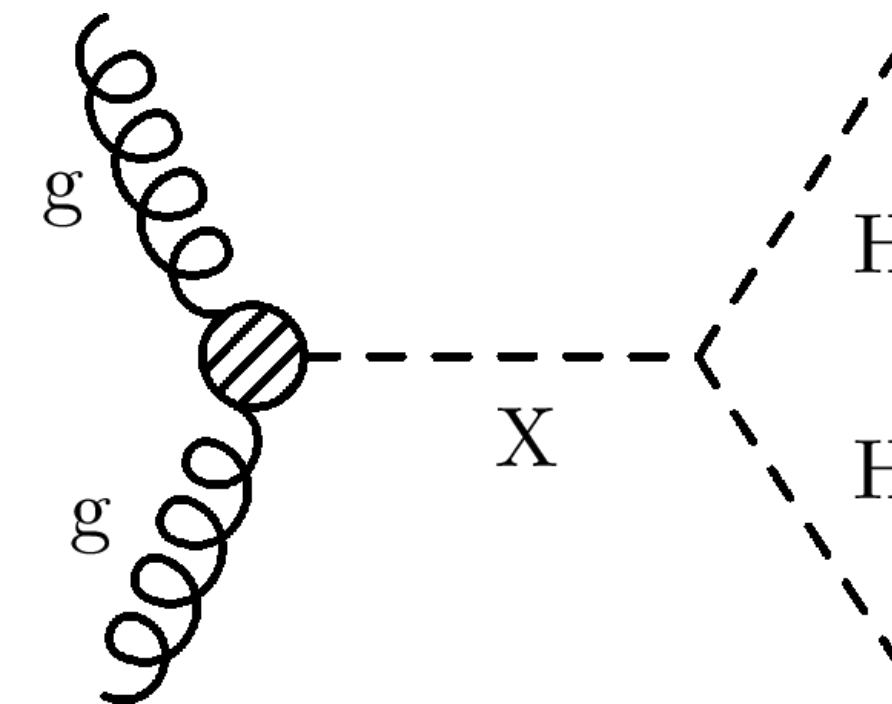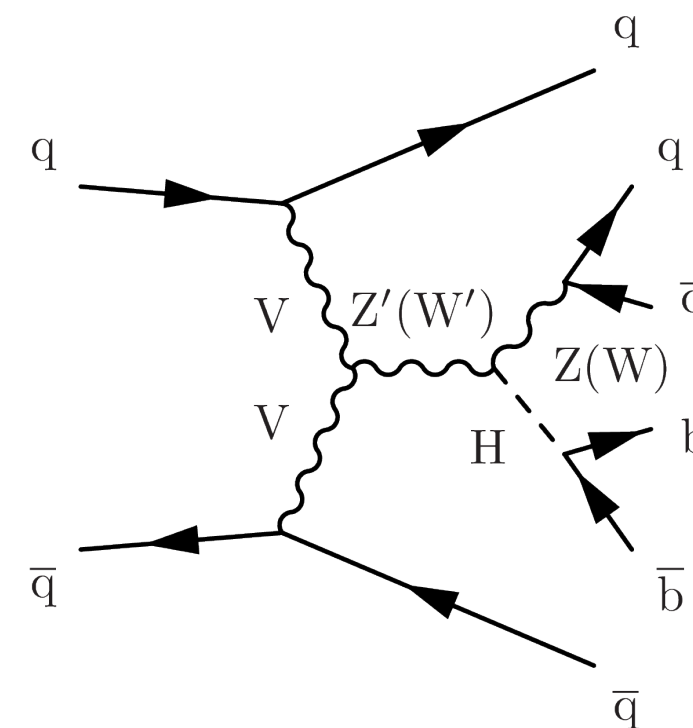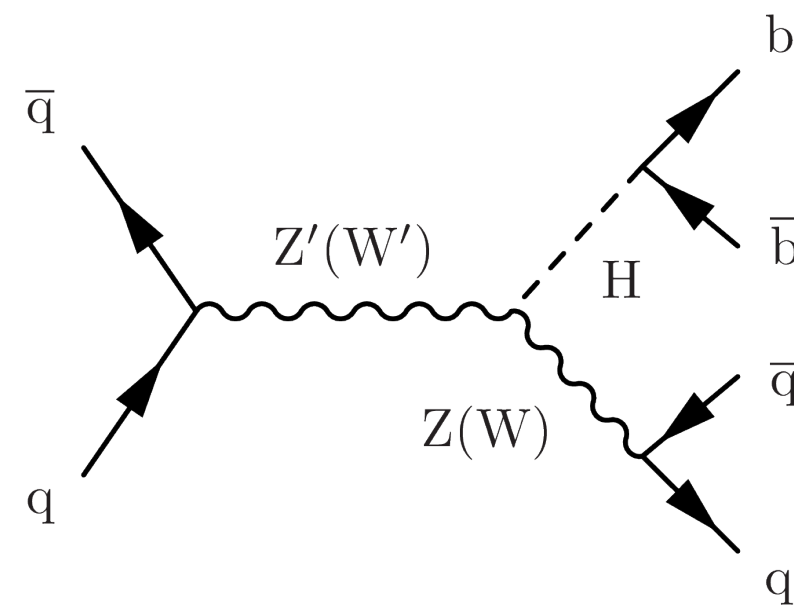
REVIEW OF $X \to YH$ SEARCHES

▸ First combination of $X \to YH$ analyses in $Y \to bb$ channel:

- 2D upper limits on masses of additional H bosons (m_X, m_Y)

- Constraints in NMSSM parameter space

▸ Review of $X \to VH$ analyses ($V = W, Z$):

- Search for heavy vector bosons V' in the mass range $1 \div 5\,\mathrm{TeV}$ in DY and VBF production mode

- Interpretation in HVT model in terms of H boson (g_H) and fermion (g_f) coupling modifiers

- Weakly coupled (A) and composite H model-inspired (B) scenarios excluded

FIRST SIMULTANEOUS MEASUREMENT OF ttZ, tZq AND tWZ

TOP-23-004
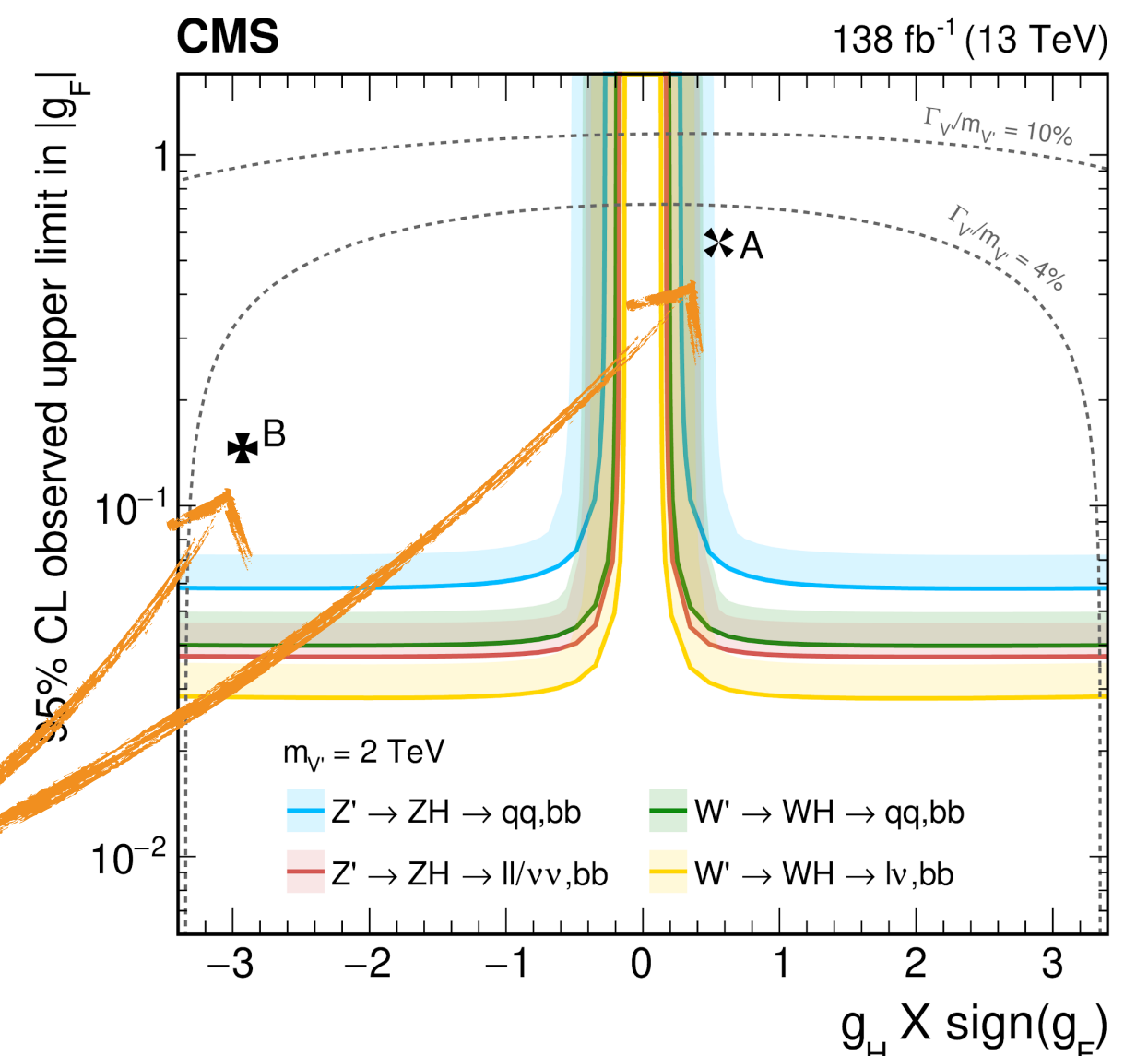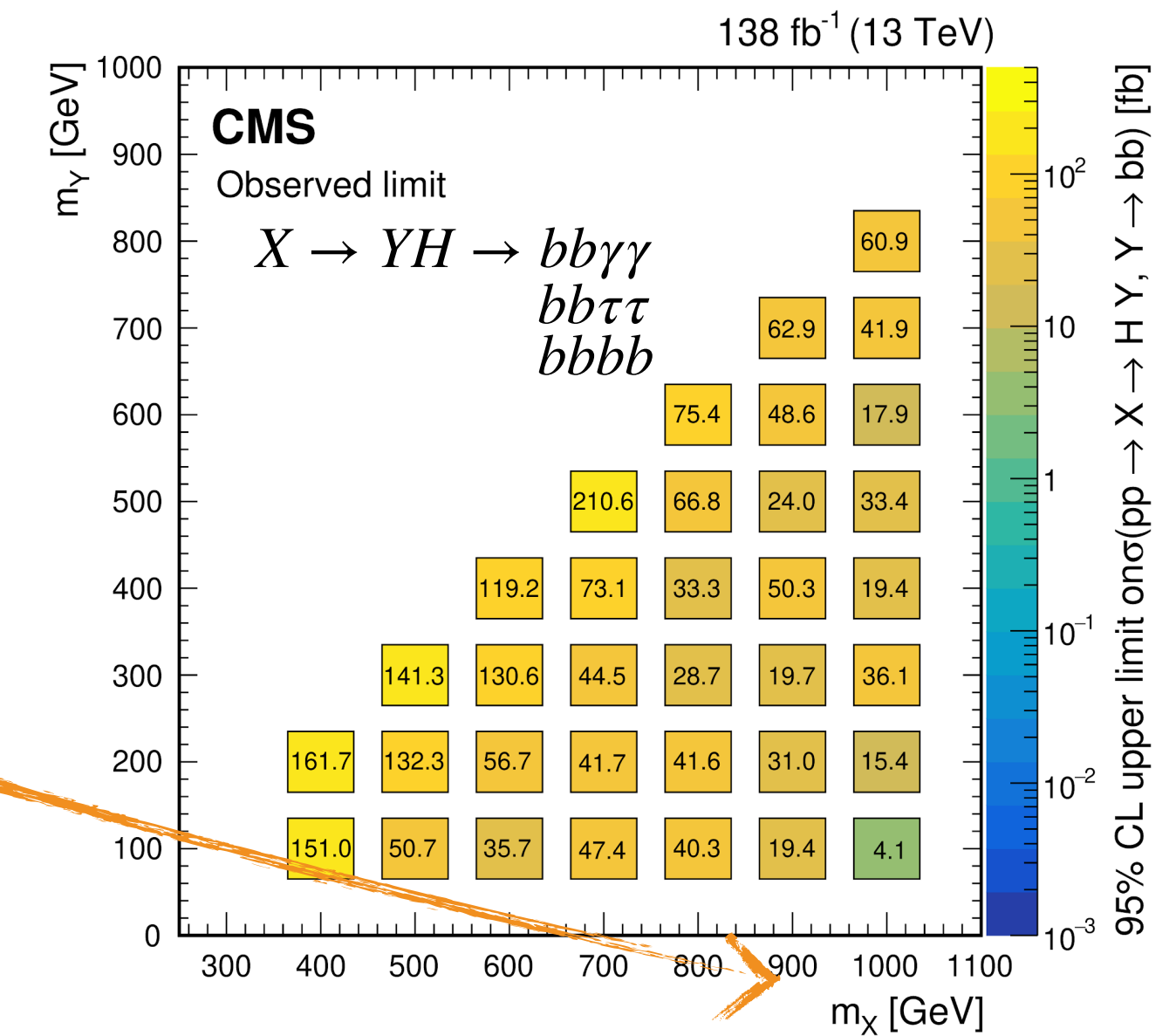
▸ **Enhance sensitivity** to anomalous tZ and tWb couplings

▸ **Consistent** measurement of **uncertainties** and **correlations**
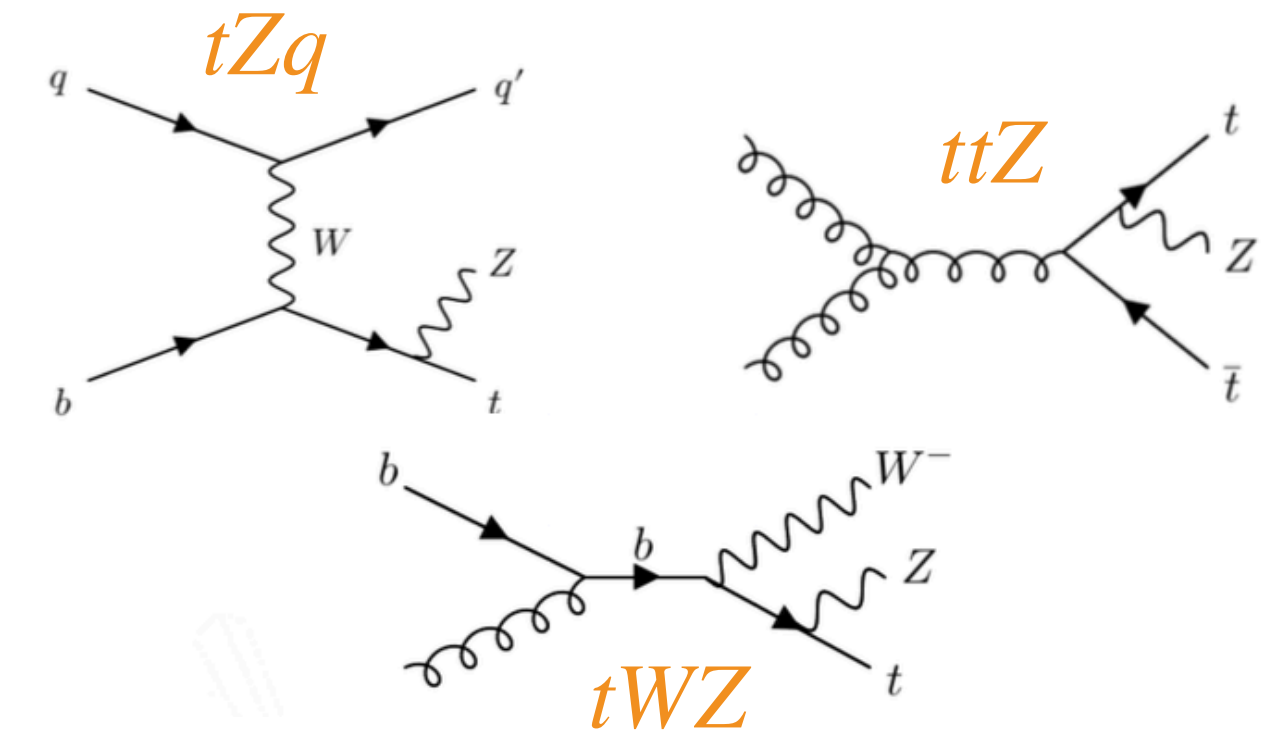
▸ ttZ interferes with $tWZ \rightarrow$ measured together

▸ Final states with 3 leptons $\rightarrow$ DNN to separate signal from. background

INCLUSIVE CROSS-SECTIONS

▸ Good agreement with SM for tZq, $ttZ + tWZ$ higher than QCD NLO predictions
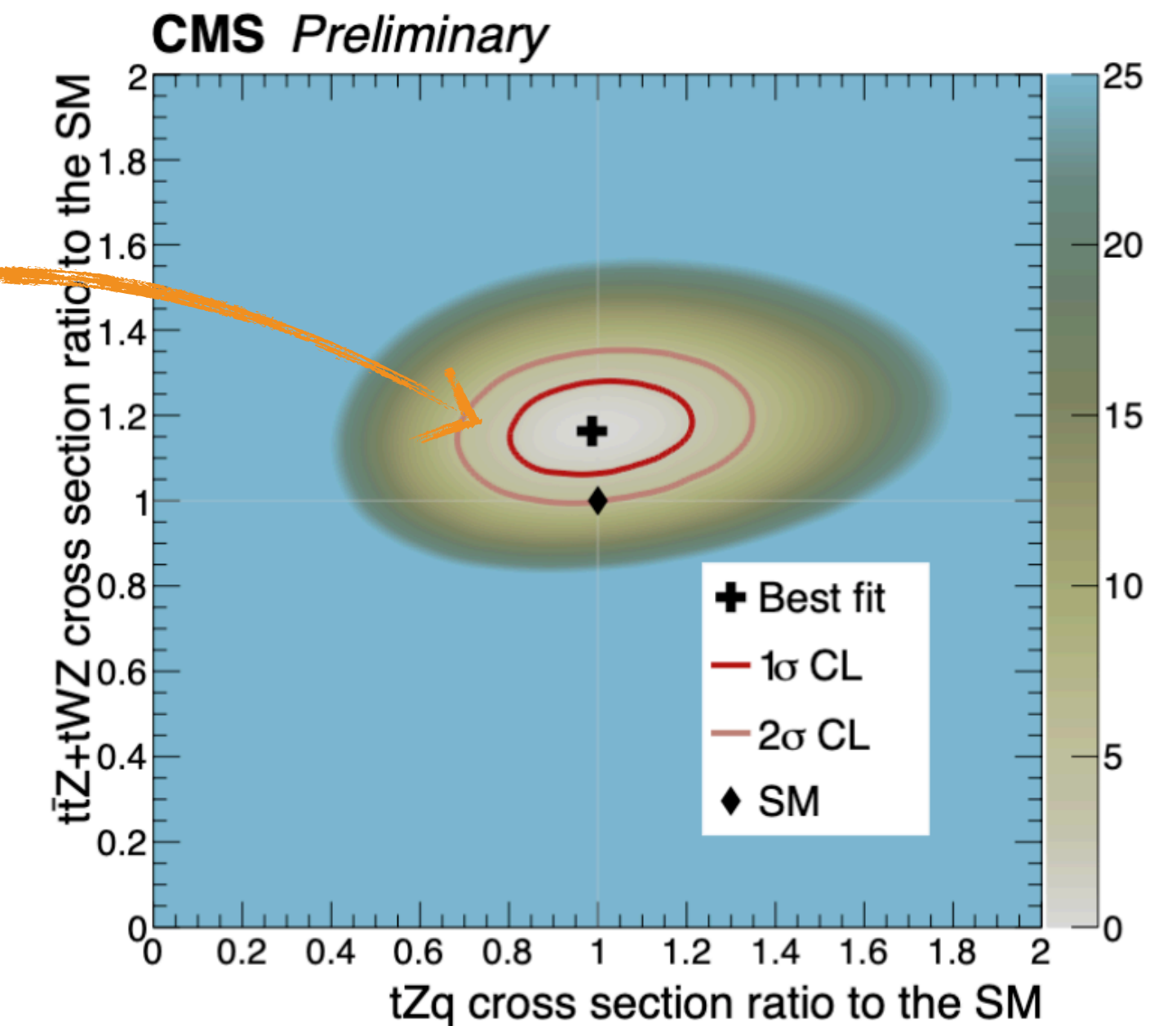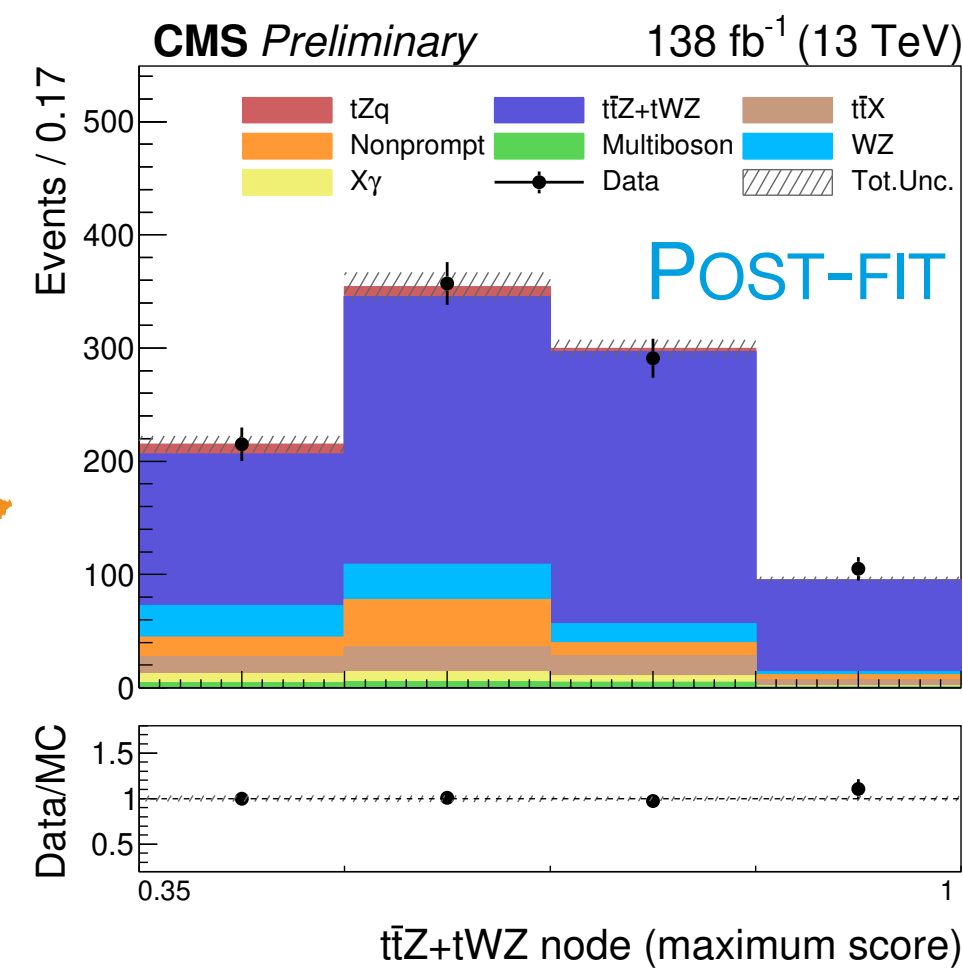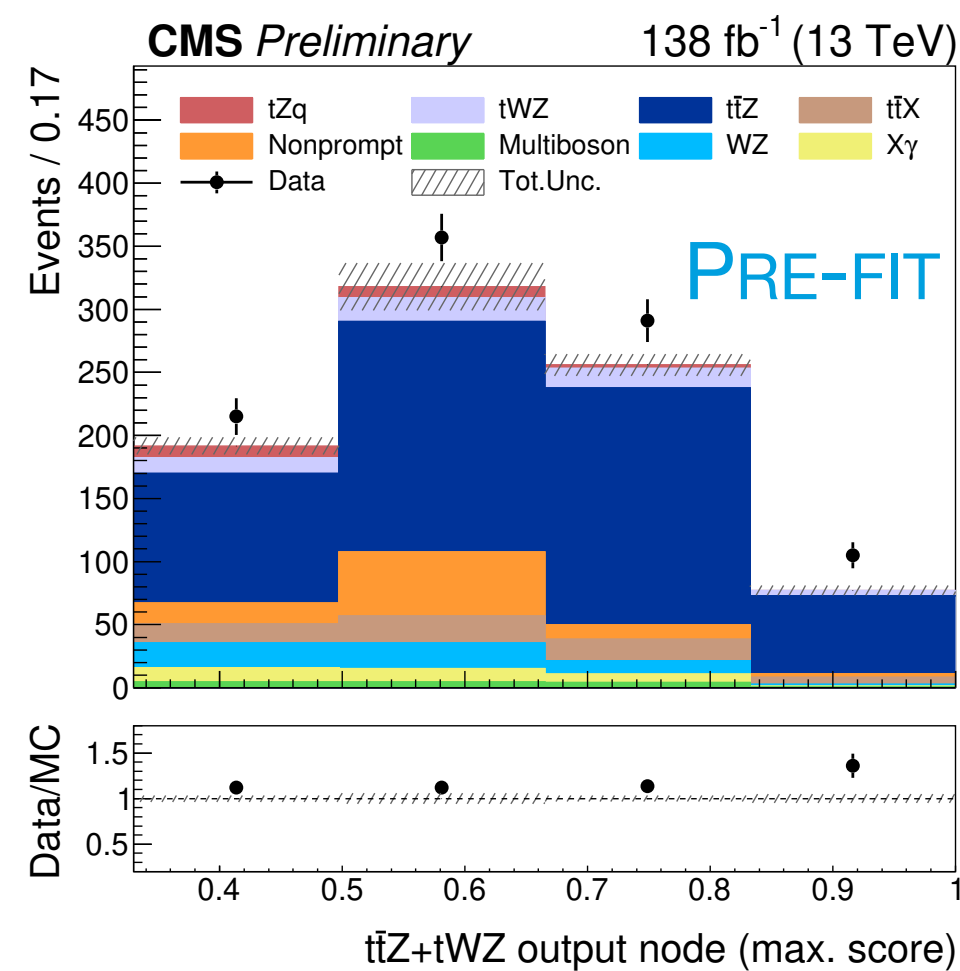
$$\sigma(t\bar{t}Z + tWZ) = 1.14 \pm 0.05 \,(\text{stat}) \pm 0.04 \,(\text{syst}) \text{ pb}$$

$$\sigma(tZq) = 0.81 \pm 0.07 \,(\text{stat}) \pm 0.06 \,(\text{syst}) \text{ pb}$$

FIRST SIMULTANEOUS MEASUREMENT OF ttZ, tWZ AND tZq

TOP-23-004

DIFFERENTIAL CROSS-SECTIONS

▸ Good agreement with SM, excess at low lepton p_T for the $ttZ + tWZ$ channel

▸ Differential measurement is still statistically limited
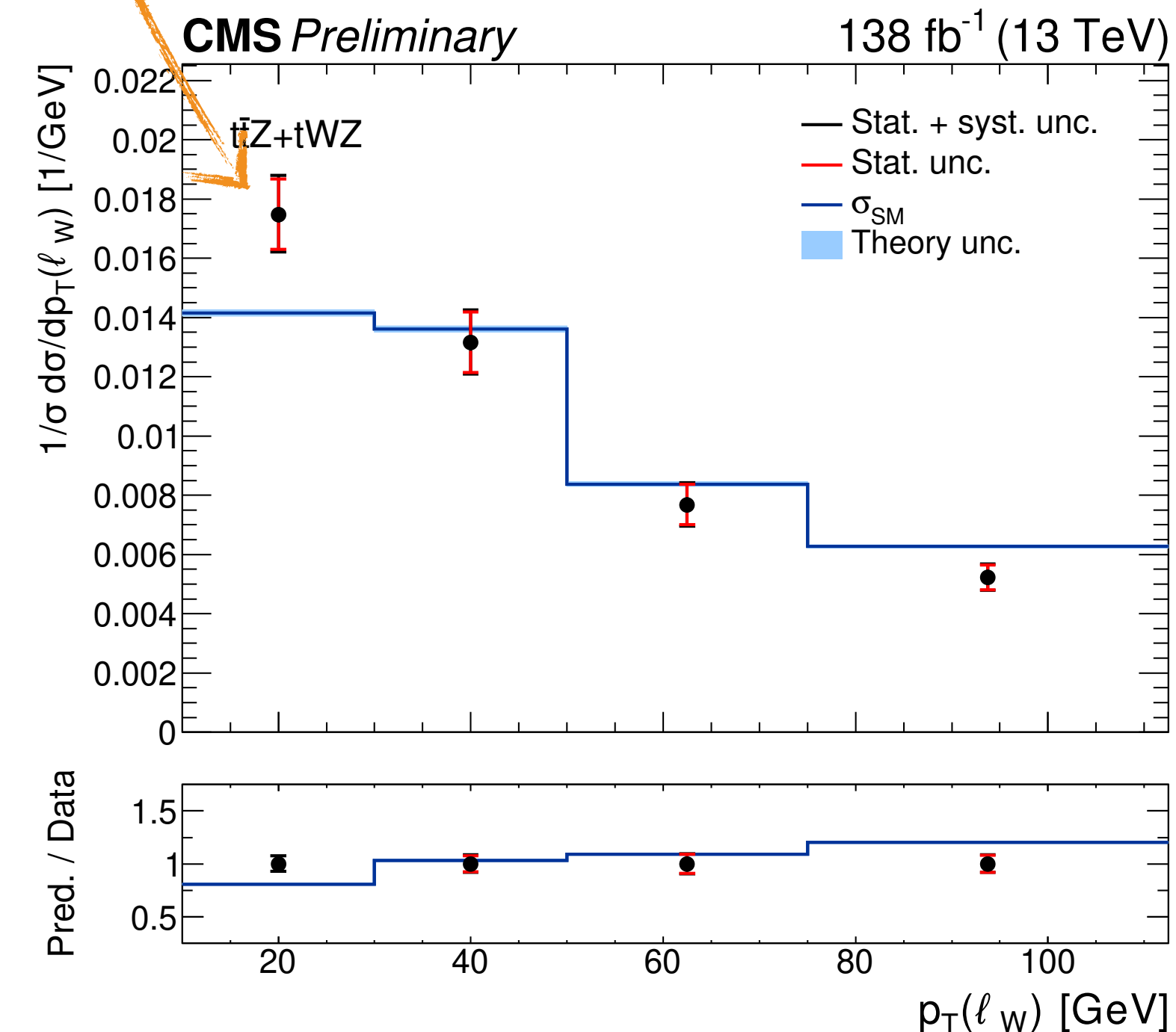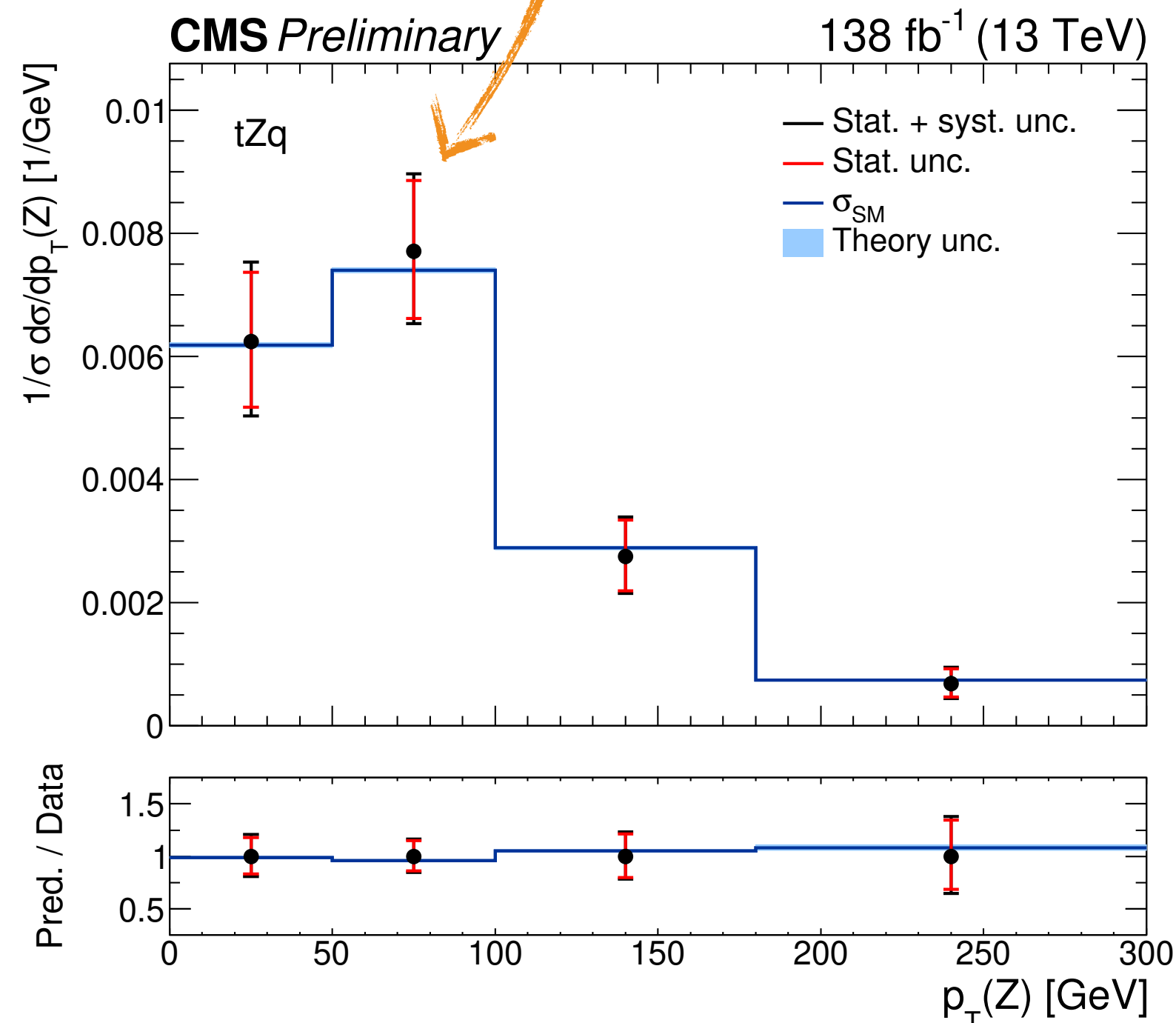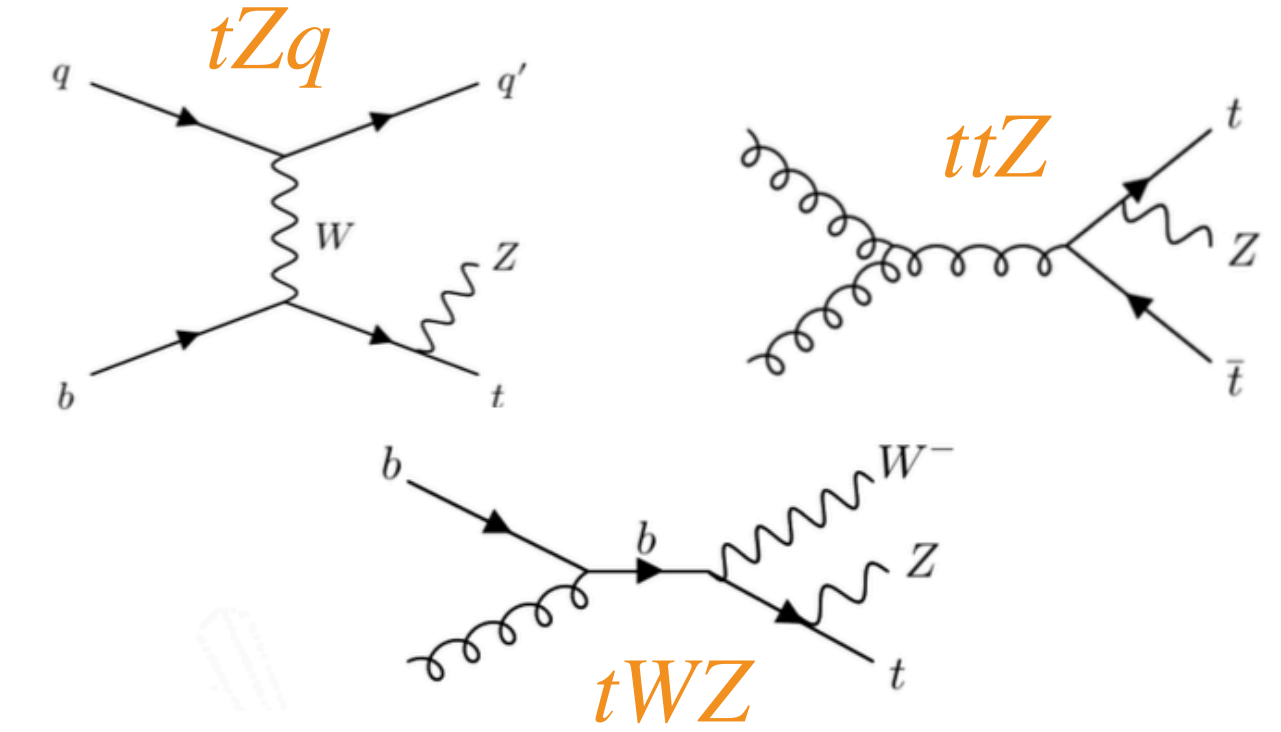
SEARCH FOR DARK MATTER PRODUCED IN ASSOCIATION WITH A SINGLE-t OR $t\bar{t}$ PAIRS

▸ Full Run 2 search targeting simplified Dark Matter (DM) model with spin-0 scalar (ϕ) or pseudoscalar (a) mediators

▸ ϕ/a couple preferentially to heavy third-generation quarks (Yukawa-like coupling) → focus on $t/\bar{t}$+DM and $t\bar{t}$+DM searches

▸ **First result** to target t+DM and $t\bar{t}$+DM signatures simultaneously across all t decay modes

- All-hadronic ($0\,\ell$)

- Semileptonic ($1\,\ell$)

- Dileptonic ($2\,\ell$)

▸ In the dileptonic channel
  → NN trained in each b-tag region and for each of the mediator hypotheses
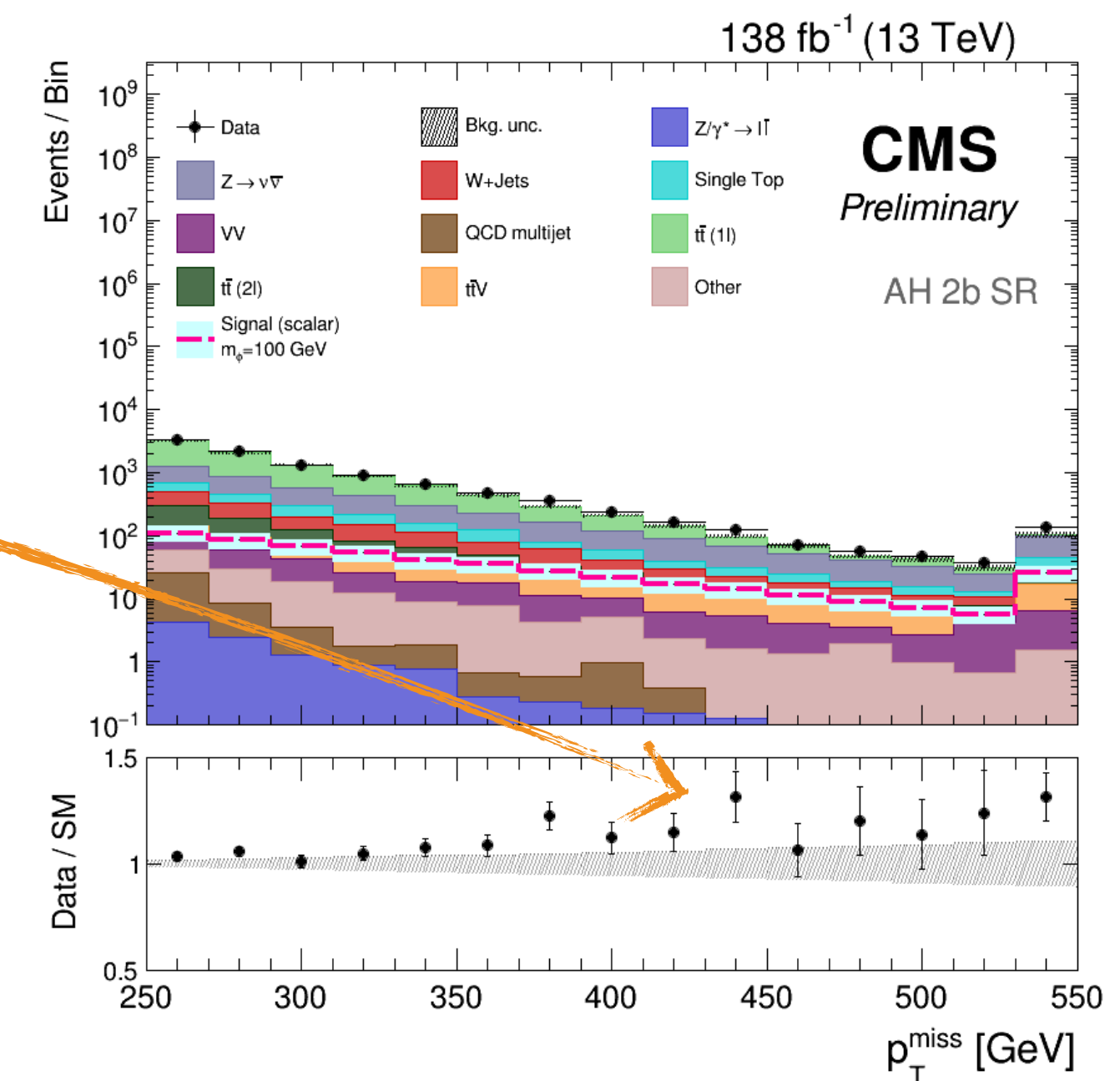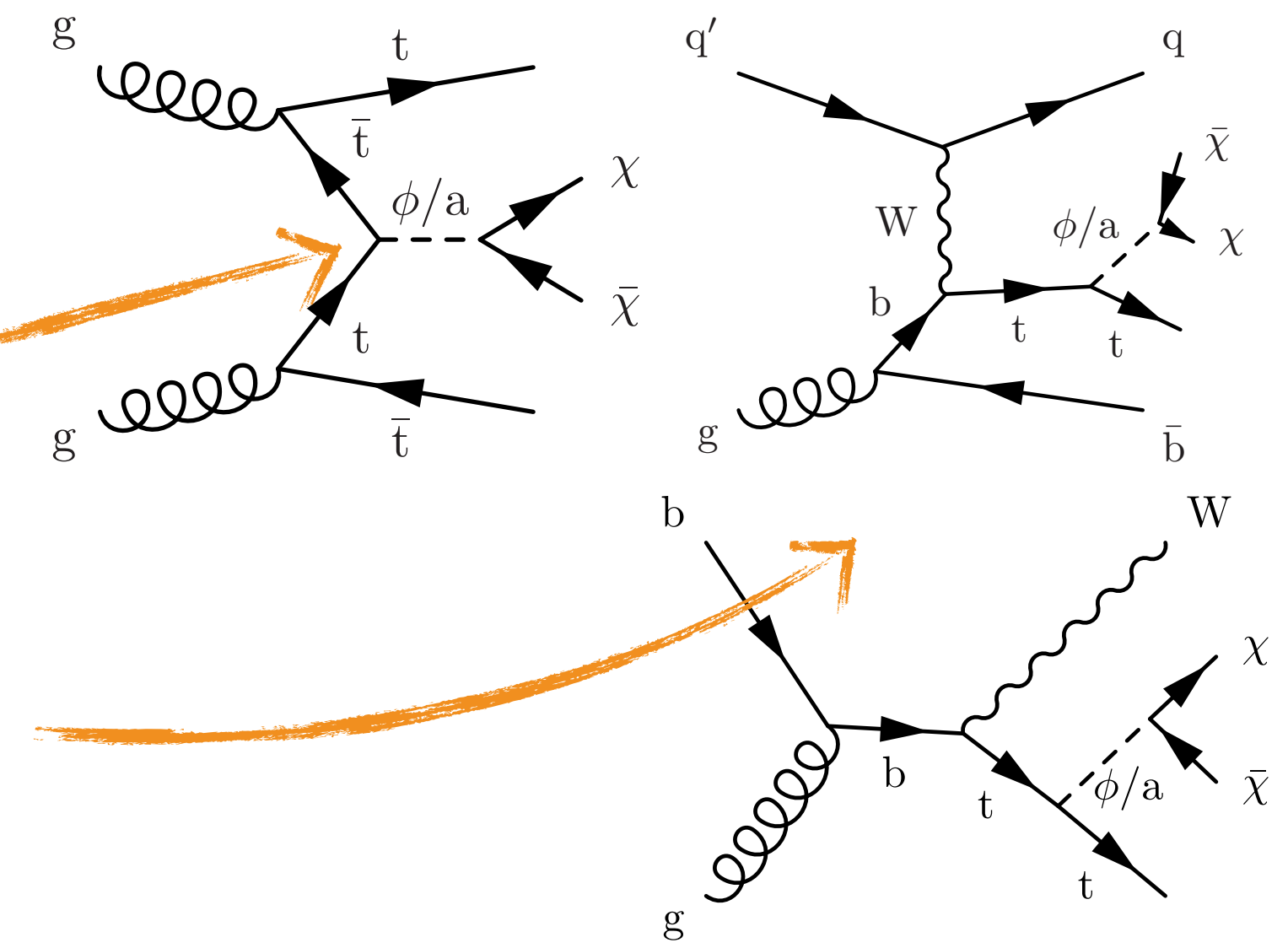
SEARCH FOR DARK MATTER PRODUCED IN ASSOCIATION WITH A SINGLE-t OR $t\bar{t}$ PAIRS

▸ Signal extracted from simultaneous fit to p_T^{miss} and to the NN output

▸ Signal-like excess (2σ) observed in data → signal kinematics are not very sensitive to the mass of the mediator, this excess is consistent with all mediator mass hypotheses

▸ Excluded mediator masses below 280 (290) GeV for the scalar (pseudo scalar) case

LHC COMPUTING

LHC COMPUTING
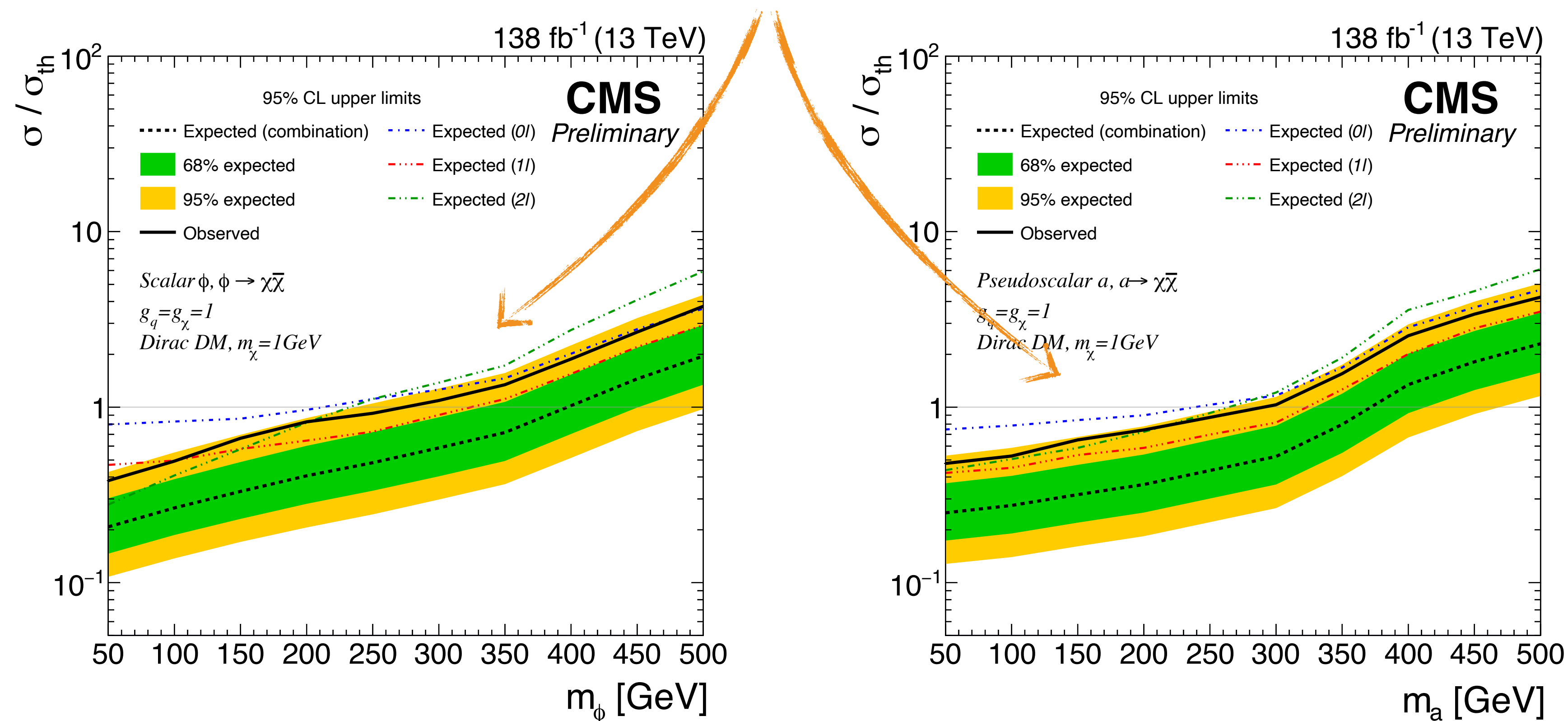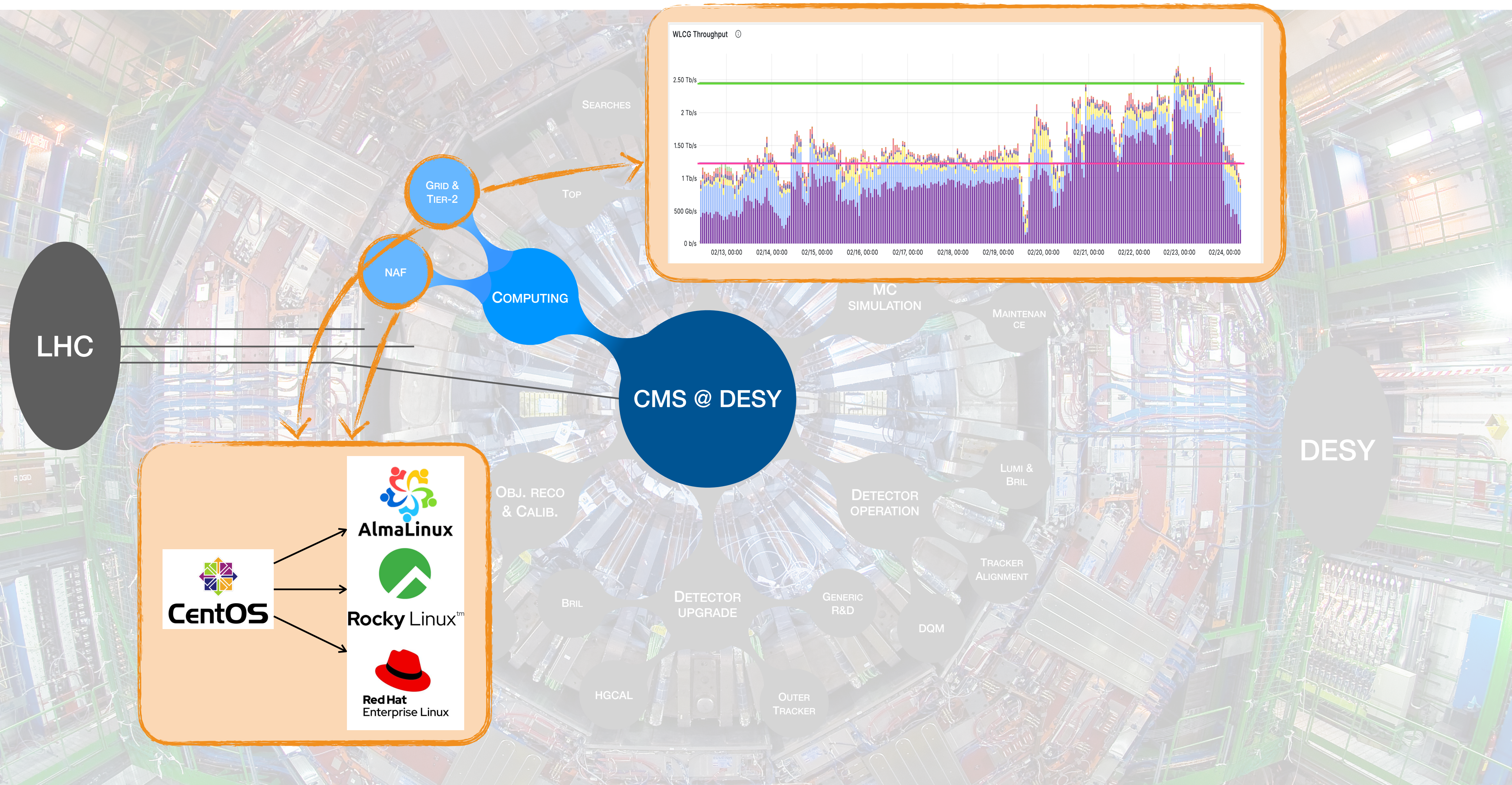
‣ **Hot topic**: WLCG migration from CentOS7 (end-of-life 30/06/2024) → EL9

‣ Not needed to fasten the seatbelt:

↻ **Grid**: migration ongoing, straightforward w.r.t. typical LHC applications (payloads running on appropriate containers)

↻ **NAF**: migration ongoing for batch and login machines → done by June (applications can still use centOS7 via containers)

‣ **WLCG pledges by DESY in 2024**:

- Increase CPU and Disk capabilities for DESY-T2

- All resources **installed**

‣ **New series of computing workshops at DESY**

- Focus on sustainability and efficient usage of resources

- Workshops: Sep '23, Jan '24, Oct '24 (beginner) + Apr '24 (advanced)

	ATLAS		CMS		LHCb	
CPU [kHS23]	63.5	+6%	84.0	+17%	22.4	+13%
Disk [TB]	6670	+20%	7380	+26%	35	/

Advanced

FH Sustainable Computing Workshop

IT WORKS ON MY MACHINE: A workshop on software testing

Are you tired of
- debugging the same things over and over?
- complaints from others that your code doesn't work?
- spending time on manually testing your code?

Come to our workshop to learn about unit testing and writing testable software

https://indico.desy.de/event/44051/
fh-forum-sustainability@desy.de

**April 26, 2024, 9-13h
Building 3, BAH1**

LHC Computing
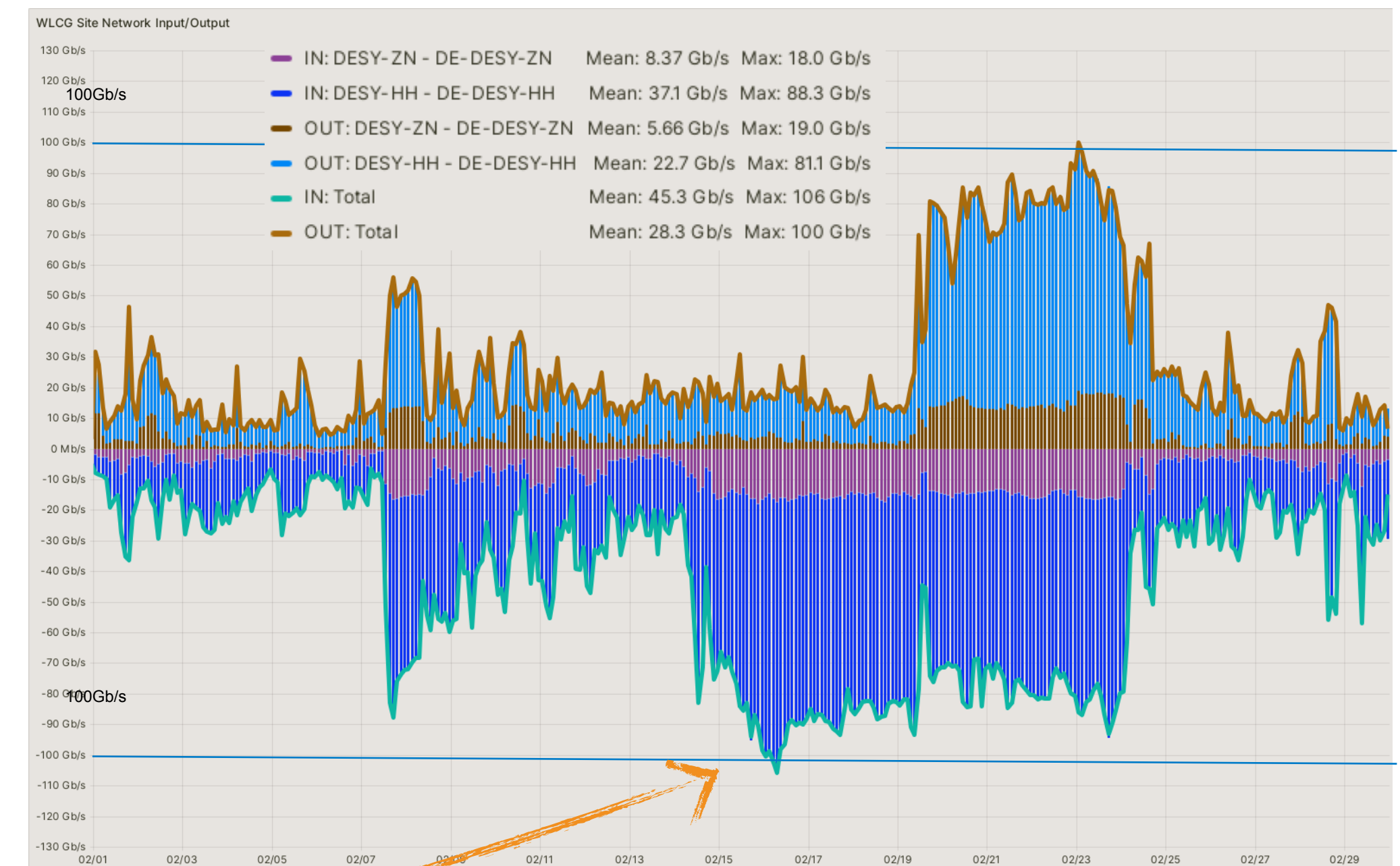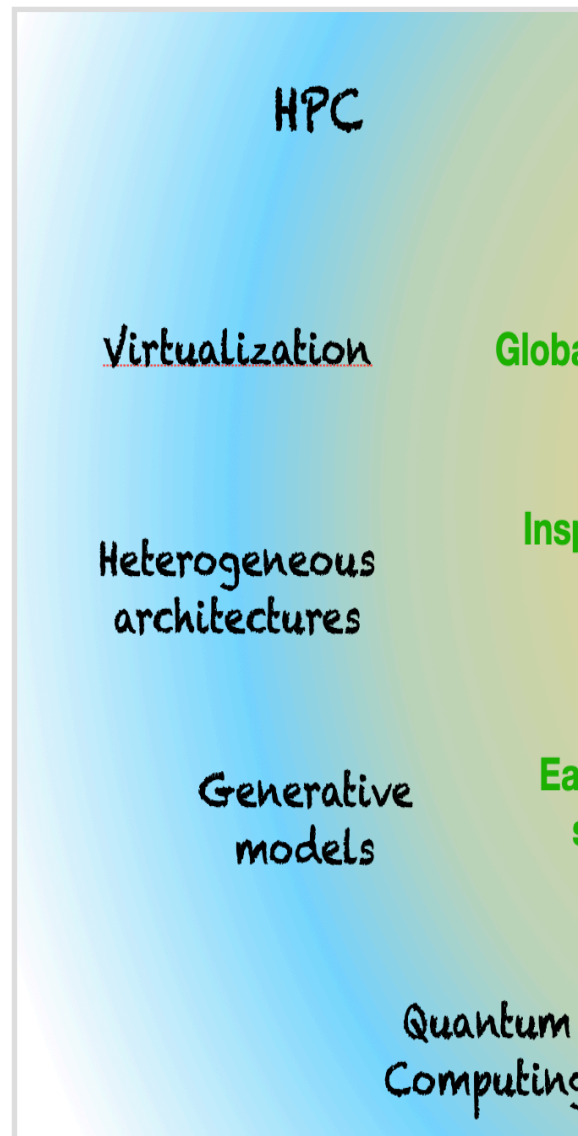
▸ WLCG data challenge to demonstrate readiness for HL-LHC → increase throughput and technical complexity over time

▸ Data challenge 2021: involved primarily T0 and T1 sites, 10% expected HL-LHC data throughput, mainly LHC exp. involved

▸ **Data Challenge 2024**:

- 25% expected HL-LHC data throughput

- Participants: LHC exp. + **Belle II, DUNE, T0/1/2 sites**

- Probed system capabilities
  → **at the boundary**

- At DESY: **smooth test**, no major problems

- Present WAN connection well-utilised
  → **upgrade needed** for coming DCs and HL-LHC

WAN throughput DESY-HH & DESY-ZNn in February 2024

WLCG Site Network Input/Output

IN: DESY- ZN - DE-DESY-ZN	Mean: 8.37 Gb/s	Max: 18.0 Gb/s
IN: DESY-HH - DE-DESY-HH	Mean: 37.1 Gb/s	Max: 88.3 Gb/s
OUT: DESY-ZN - DE-DESY-ZN	Mean: 5.66 Gb/s	Max: 19.0 Gb/s
OUT: DESY-HH - DE-DESY-HH	Mean: 22.7 Gb/s	Max: 81.1 Gb/s
IN: Total	Mean: 45.3 Gb/s	Max: 106 Gb/s
OUT: Total	Mean: 28.3 Gb/s	Max: 100 Gb/s

FH PLATFORM OF SCIENTIFIC COMPUTING

▸ Horizontal structure across all scientific FH groups

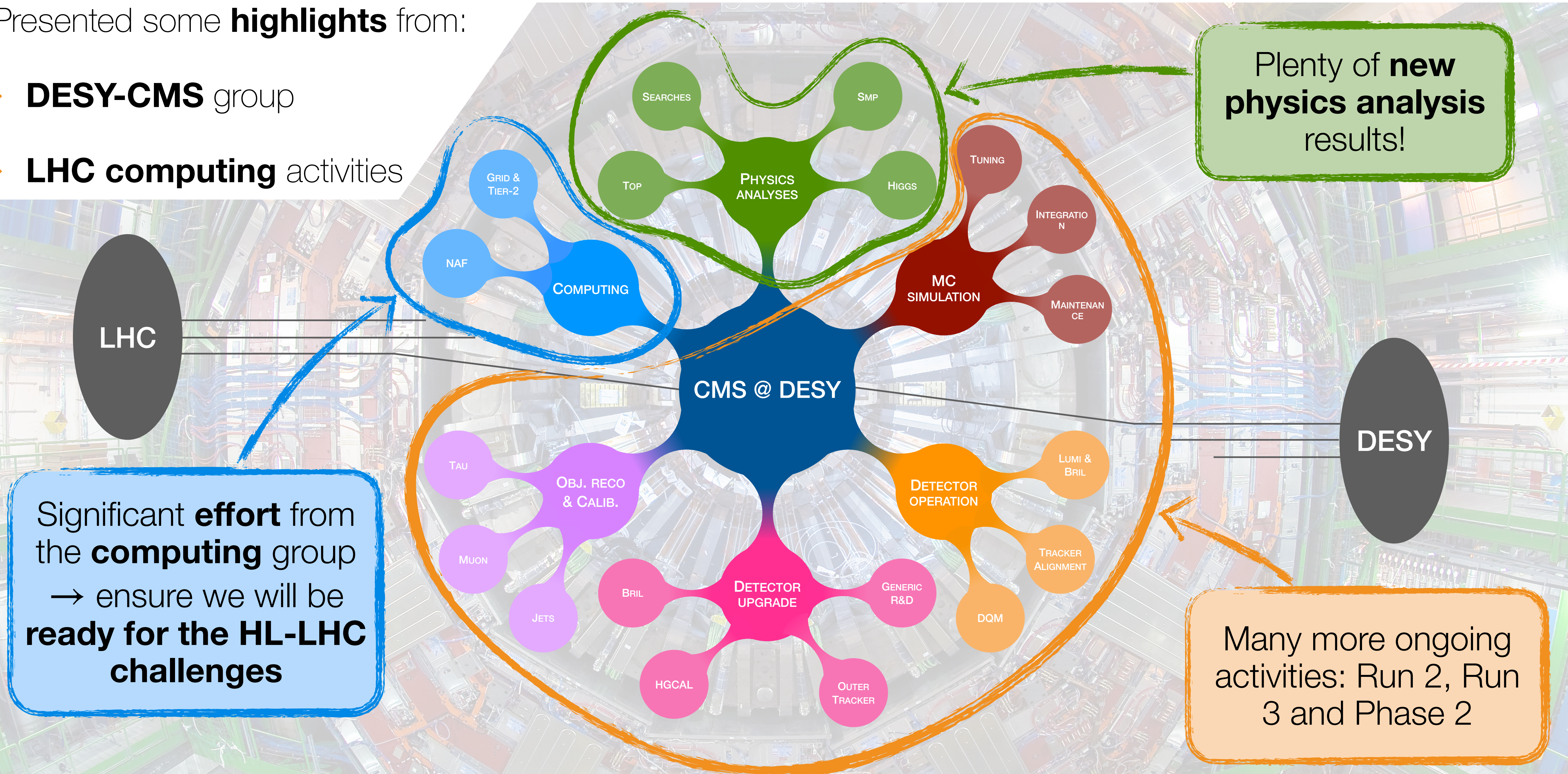- **Identify** and exploit **synergies** + **priorities** for scientific computing (SC)
  → activities in agreement with the European Strategy for Particle Physics and wider DESY strategy

- Ensure **good communication** across FH groups

- Act as **liaison** to **internal** and **external SC activities** (MT-DMA, WLCG, HSF, ITT, …)

- **Coordinate** selected cross-group SC projects

- **Explore** SC-related related 3rd party funding opportunities

- **Organize** SC workshops and tutorials, etc.

▸ Steering group

- 12 members across FH

- Bi-weekly meeting to kick off platform activities

FH SciComp Workshop

01–02 lug 2024
DESY Campus Hamburg
Europe/Berlin fuso orario

[Indico]
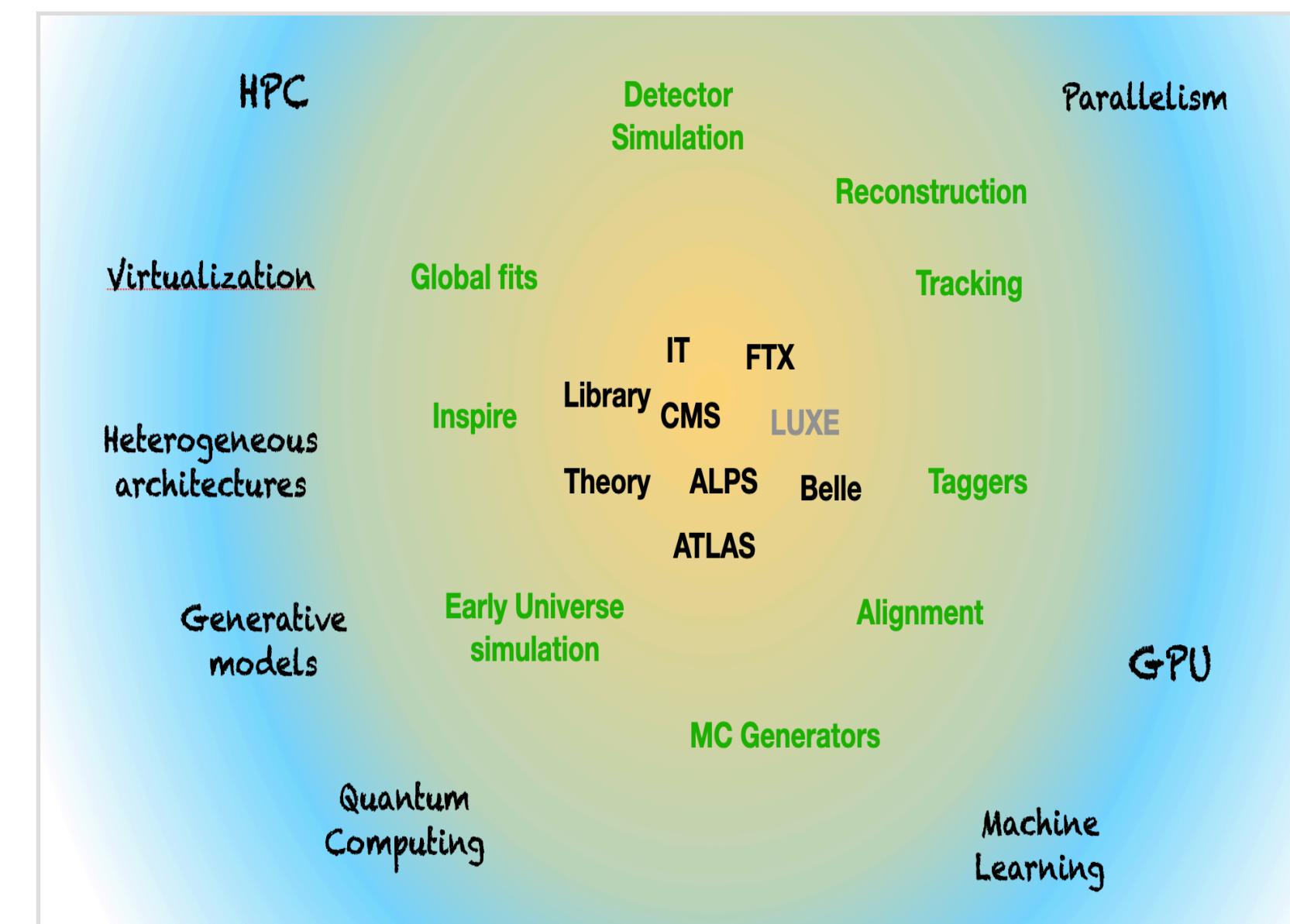
SUMMARY

Presented some **highlights** from:

▸ **DESY-CMS** group

▸ **LHC computing** activities

Plenty of **new physics analysis** results!

Significant **effort** from the **computing** group → ensure we will be **ready for the HL-LHC challenges**

Many more ongoing activities: Run 2, Run 3 and Phase 2

ADDITIONAL MATERIAL

DC24 WLCG THROUGHPUT

WLCG Throughput ⓘ

	max	avg ∨	current
● Data Challenge	2.19 Tb/s	1.02 Tb/s	211 Gb/s
● atlas	625 Gb/s	304 Gb/s	567 Gb/s
● alice xrootd	349 Gb/s	115 Gb/s	71.4 Gb/s
● cms xrootd	191 Gb/s	67.4 Gb/s	42.7 Gb/s
● cms	271 Gb/s	57.2 Gb/s	75.0 Gb/s
● belle	38.9 Gb/s	9.45 Gb/s	17.1 Gb/s